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THE EFFECTS OF EMISSION CONTROL DEVICES ON THE POLYNUCLEAR AROMATIC HYDROCARBON AND MUTAGEN LEVELS IN DIESELIZED UNDERGROUND MINES

DSS Contract 03SV.23440-3-9175/1

and

THE DETERMINATION OF THE PAH PARTITION RATIO AND THE NATURE OF MUTAGENS GENERATED BY CATALYTIC PURIFIERS

DSS Contract 03ST.23440-3-9196

L.A. Baldisera

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ABSTRACT

The effect of several different types of exhaust treatment devices; a Johnson Matthey-Engine Control Systems catalytic trap oxidizer, a fume diluter, a catalytic trap oxidizer-fume diluter combination, a PTX catalytic converter and a Corning Diesel Exhaust filter have been tested on Deutz 714 diesels in two different underground mines in order to learn how these devices affect the concentrations of the polynuclear aromatic hydrocarbons and the mutagens in the mine air. The PAH concentrations on board the diesel in the operator's breathing zone have also been determined. Finally, these devices have been assessed with respect to their sulfuric acid emissions and the RCD downstream from the diesel.

The results show that the CTO and the Corning filter are superior to the PTX catalyst that is common on most of the diesels used in underground mines. The fume diluter has significant advantages for the scoop tram operator. In fact, a combination of a fume diluter and an improved CTO or a Corning Diesel Exhaust filter may prove to be an excellent exhaust treatment system for improving the working environment in underground mines.

INTRODUCTION

Several new types of exhaust treatment devices have recently been developed for the diesels used in underground mines.[1,2] These devices, which attempt to reduce the levels of particulate and other pollutants in the diesel exhaust have ranged from a better catalyst,[1] to a filter,[2,3] to a fume diluter whose only function is to blow the pollutants away from the operator thus reducing his exposure. Each type of exhaust treatment device, singly and in combination, has been evaluated to determine which configuration is best from an industrial health point of view.

The actual work has involved determining the PAH and mutagen levels in the air downstream from Deutz 714 series diesels fitted with 1) a Johnson Matthey-Engine Control Systems catalytic trap oxidizer (CTO), 2) a PTX catalytic converter, 3) a Corning Diesel Exhaust filter, 4) a fume diluter and 5) a CTO and fume diluter in series. In addition, the sulfur emissions and the RCDs were determined downstream from diesels operating with the different types of exhaust treatment system. Finally, the PAH concentrations in the air in the breathing zone of the scoop tram operator were determined for most of these exhaust treatment devices.

RESULTS AND DISCUSSION

EXPERIMENTAL DESIGN

LOCATION OF THE TESTS

This study was carried out in two different mines. The Johnson Matthey-Engine Control Systems catalytic trap oxidizer (CTO) and the fume diluter were tested on a 145 horsepower A6L-714 Deutz diesel in a stope on the 2250 foot level of Falconbridge Limited's Strathcona Mine, Figure 1. The sampling site was at the end of the stope, approximately 2 meters in front of the exhaust air raise, for all tests. This design ensured that all the exhaust passed the sampling site. The LHD cycle began by loading muck at muck pile A and transporting it to muck pile B where it was dumped. The LHD cycle was completed by loading muck at muck pile B and dumping it at muck pile A. The muck piles were placed against the wall of the stope so that a lug down could be included in each loading operation and so the end of the exhaust pipes of the diesel were in the center of the stope during each loading operation. This design ensured that all of the exhaust was emitted on the direct line between the air intake and exhaust ports of the stope. This meant that all of the exhaust should travel directly to the samplers at the sampling site.

The LHD cycle is described in Figure 1. The average LHD cycle lasted 78 ± 36 seconds. There was a lug down of approximately 15 seconds at each muck pile and it took approximately 10 sec to dump the ore at each muck pile. The remaining time (approximately 30 sec) was spent tramming with a loaded bucket.

The ventilation rate was 16,840 ± 720 cfm (an average of 116 cfm/bhp) during these tests. The intake air to the stope was obtained directly from a fresh air raise and was not contaminated with air from any other working environment. Moreover, the carbon dioxide (CO_2) level in the intake air was

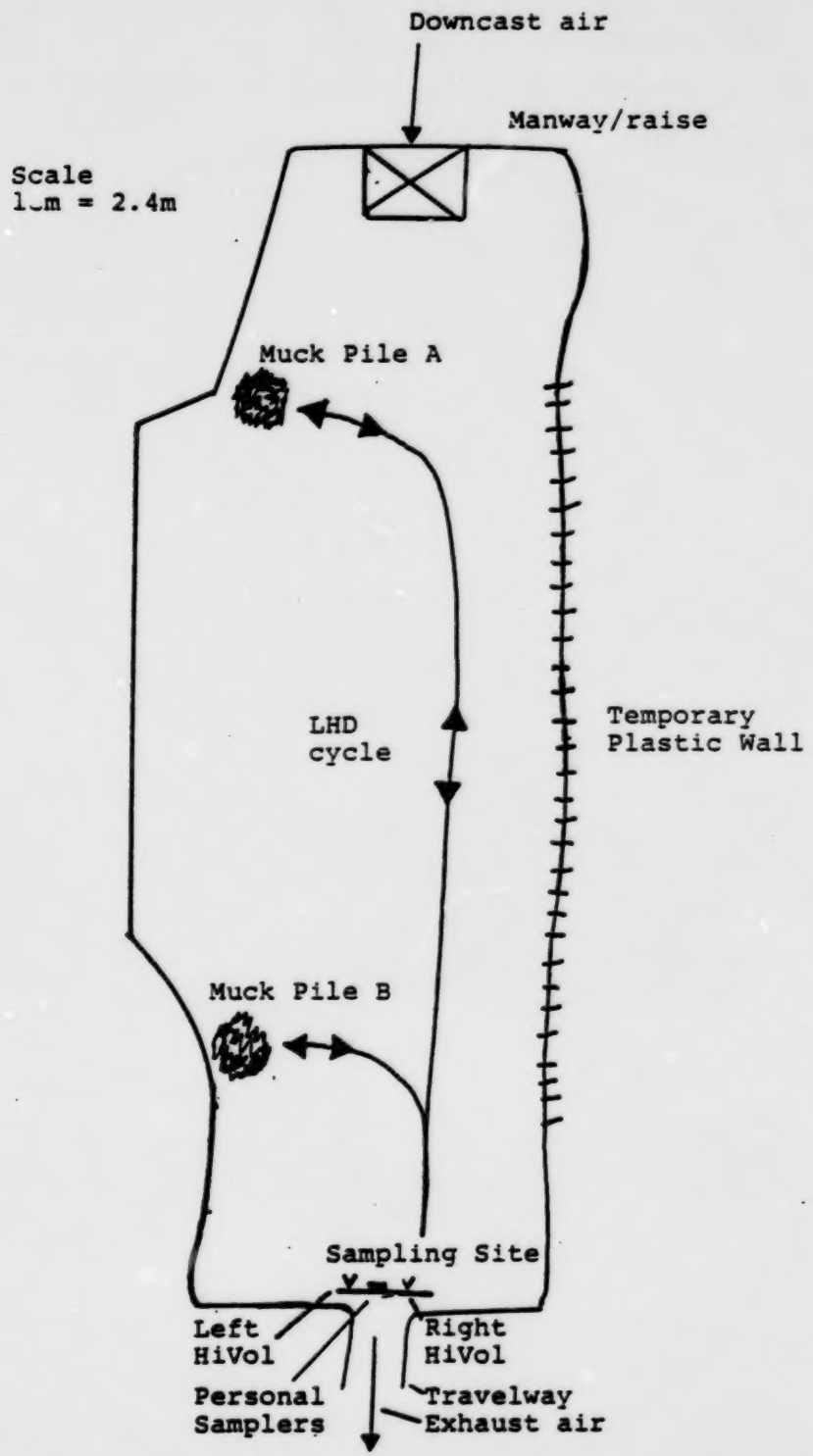

Figure 1 Sampling Site at Falconbridge Limited's Strathcona Mine 23-E2-E4 stope

always at ambient air levels of 0.03% even though the air was heated; the heating was done with a sealed heat exchanger rather than by passing the air through a furnace. This meant that the dilution ratios calculated from the time-weighted average CO_2 concentrations at the sampling site were accurate estimates of the average dilution ratio of the diesel exhaust at the sampling site.

The Corning Diesel Exhaust filter and the PTX catalyst, on the other hand, were tested on a 195 horsepower F8L-714 Deutz diesel working in a production stope on the 1400 foot level of Inco Metals Company's Little Stobie Mine, Figure 2. Since this was a production stope, the level plan was always changing and the samples had to be collected at several different sampling sites. Because the ore was hauled for different distances, i.e., the ore was either taken to the train or dumped at an alternate loading site B, Figure 2, each LHD cycle was different. However, the mucking operation was standard in several respects. For example, the mucking operation lasted approximately 30 seconds in each experiment. In addition, the ventilation was maintained at 33,000 cfm (169 cfm/bhp) throughout the tests. Finally, the sampling site was in the same general location with respect to the muck pile in each sampling environment.

One problem arose in determining the dilution factor for the exhaust in this environment. These tests were done in the winter when the intake air was heated by passing it through a natural gas furnace. This added CO_2 to the intake air and made it difficult to determine the amount of CO_2 added to the mine environment by the diesel. Because the intake air CO_2 concentrations were not available for some experiments, it was impossible to calculate an accurate dilution factor for the exhaust at the sampling site.

SAMPLING SYSTEMS

Two different types of sampling systems were used in this study. Modified High Volume (Hi Vol) samplers were used to collect samples at the sampling site while portable, battery operated personal samplers were used to collect samples on board the diesel in the breathing zone of the operator.

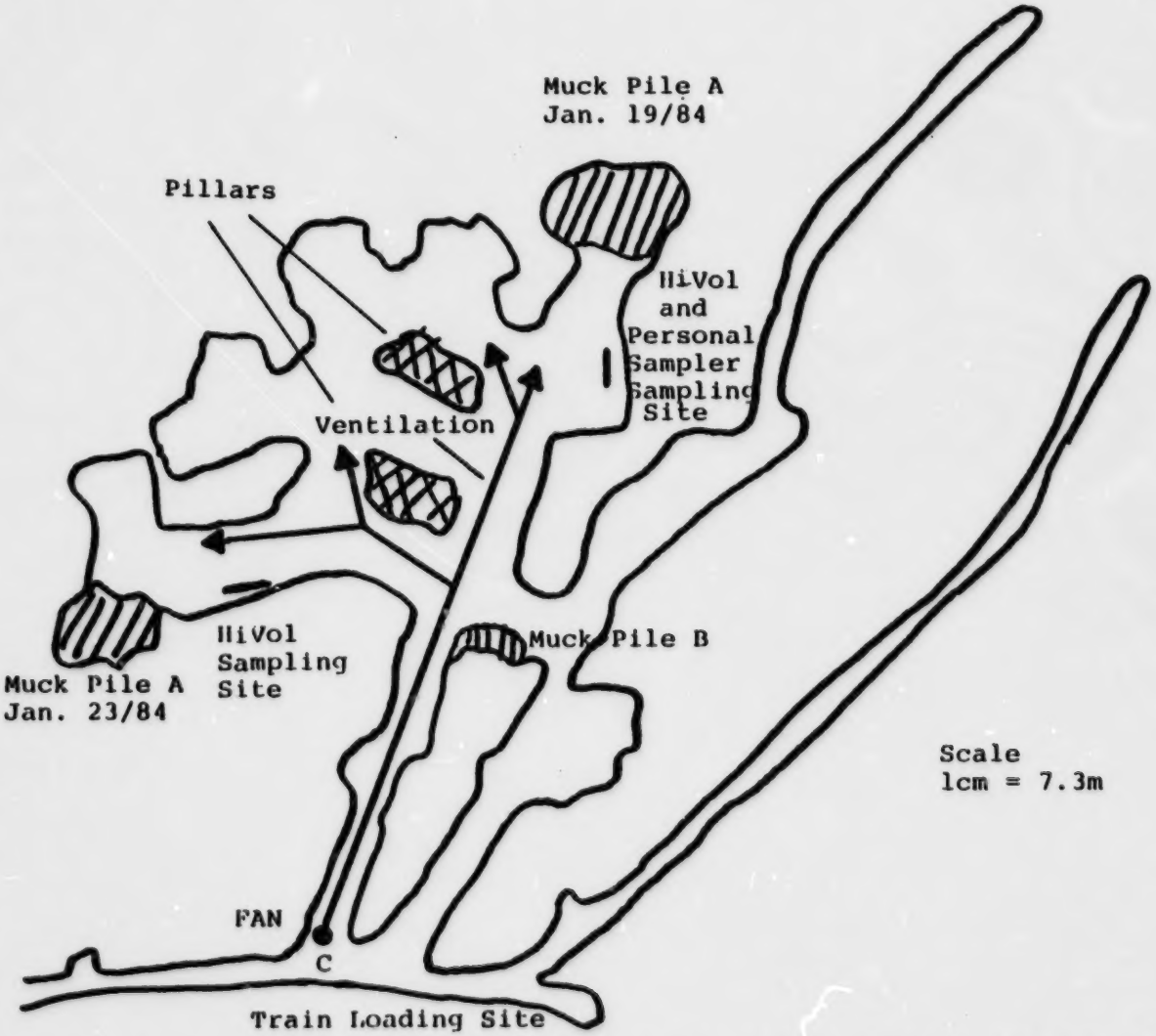

Figure 2. Sampling Sites at Inco Limited's Little Stobie, 1400' Level

Both the Hi Vol and personal sampler samples consisted of two separate samples; a filter sample and a gas adsobent (resin) sample collected in the air that had passed through the filter. For the Hi Vol sample, the sampling system consisted of an 8" by 10" Pallflex T60A20 teflon coated glass fibre filter. This was followed by a stainless steel box that contained a rectangular spider with inlet nozzles at the corners, Figure 3. The spider was connected via tygon tubing and a screw on adapter to a 1" O.D. stainless steel tube that had a 100 mesh screen soldered at the lower end. This tube contained at least 55 mL of freshly cleaned Amberlite XAD-2 ion exchange resin which is capable of absorbing PAHs.[4,5] This tube containing the gas absorbent was connected via another screw on adapter and tygon tubing to a small Neuberger vacuum pump which drew approximately 19 L/min of air through the gas absorbent.

The design of the stainless steel tubes was based on work reported by Stump and coworkers.[4] Stump et al. used XAD-2 resin in several different containers to try and trap the hydrocarbons in automobile exhaust that had passed through the particulate filter in their sampling system. These workers found that gaseous decane, undecane and diesel fuel could be trapped and recovered from XAD-2 resin quantitatively. Stump's XAD-2 hydrocarbon traps were operated at flow rates of between 40 and 95 cm/sec. Since the XAD-2 resin was capable of absorbing the aliphatic hydrocarbons quantitatively, it was assumed that they would also absorb the PAHs quantitatively. Thus, the XAD-2 traps used in this study were designed so that the mine air would be drawn through the resin bed at a flow rate of approximately 62 cm/sec, i.e., near the slowest of the velocities used by Stump et al. Because Stump's work had shown that the XAD-2 absorbed aliphatic hydrocarbons quantitatively and the flow rate was lower than those used by Stump, it was assumed that the resin would absorb any PAHs that passed through the Hi Vol filter quantitatively.

The Hi Vol sampling procedure involved measuring the flow rates through the filter and the XAD-2 gas adsorbent with water and mercury manometers, respectively, at the beginning of the sampling period. The Hi Vol was run until the flow through the Hi Vol filter had decreased to approximately 80% of the original value. Then, both the Hi Vol and the Neuberger (XAD-2 resin sample) vacuum pump were shut off, the Hi Vol filter removed, folded so the

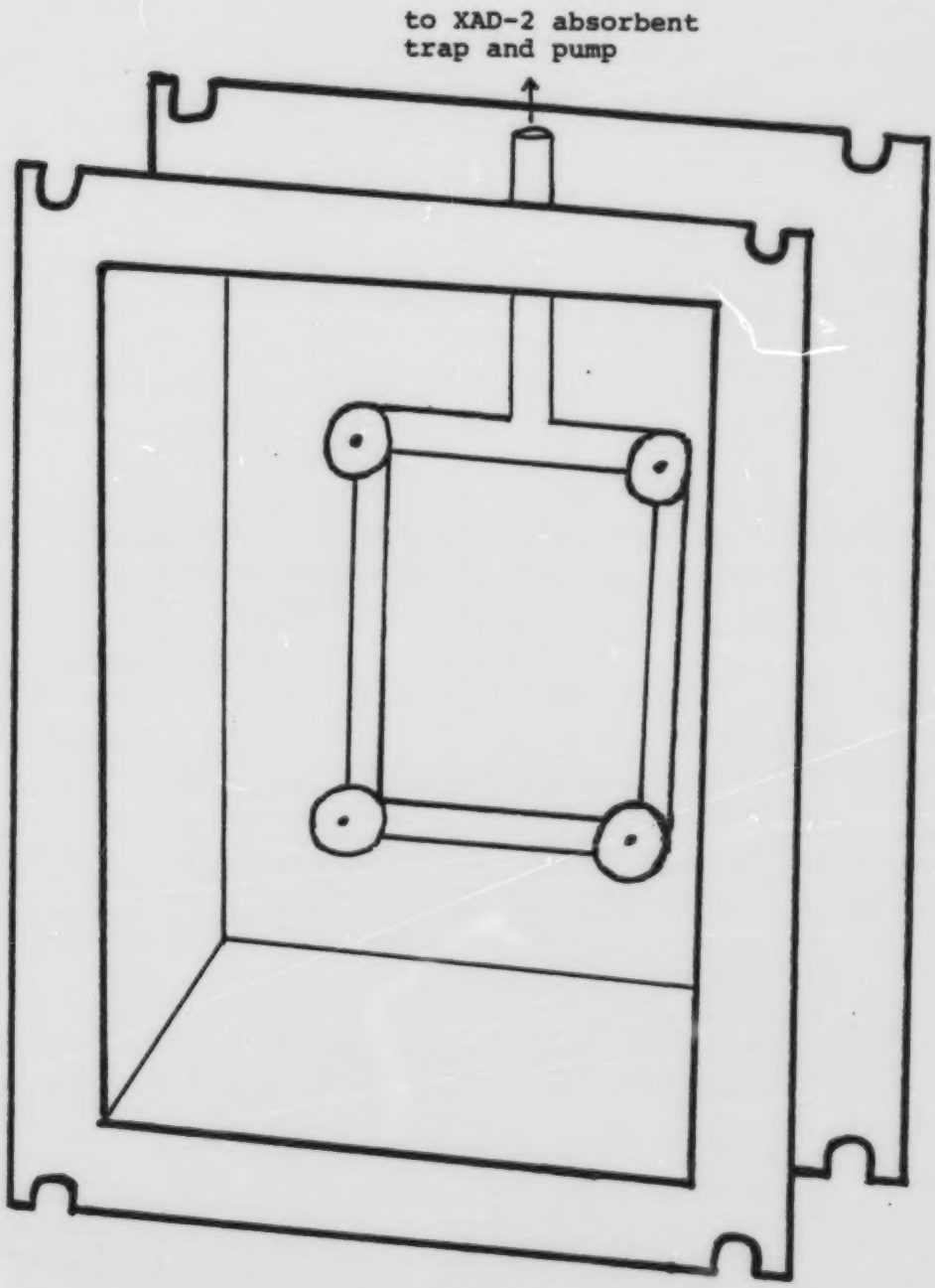

Figure 3 The spider located in the intake port of the Hi Vol sampler

particulate was on the inside of the filter, and placed in a sterile polyethylene bag. A new filter was placed on the Hi Vol sampler and the Hi Vol and the Neuberger pump were restarted. This process was continued until the end of the sampling period; usually until the end of a shift. The same resin was used for the whole sampling period even if it lasted more than a single shift. Thus, each filter sample consisted of several Hi Vol filters. In each experiment, two Hi Vol (filter and resin) samples were collected simultaneously at the sampling site. The Hi Vols were separated by at least six feet so they would not interfere with each other. For most of the samples, the Amberlite XAD-2 resin from the two resin samples which were collected simultaneously, i.e., from the two Hi Vols that were collected simultaneously, were combined into a single sample. This was done in the hope that the extract from the resins would contain enough PAHs so that they could be detected in the PAH and Ames assays.

The samples collected on board the diesel were collected in the breathing zone of the scoop tram operator. This was accomplished by collecting personal sampler samples, Figure 4, consisting of a 37 mm cassette containing a 37 mm Pallflex T60A20 teflon coated filter followed by a 12 mm diameter by 10 cm long glass tube which was tapered at each end and a low flow, battery operated, Bendix or Dupont personal sampler pump. The glass tube had a small piece of glass wool at the lower end and contained 8 mL of freshly purified Amberlite XAD-2 resin[4,5]. The cassette, the glass resin tube and the personal sampler pump were connected by short lengths of Teflon tubing and the apparatus was supported on a retort stand. In practice, seven of these portable samplers were clamped on each retort stand. Several retort stands were placed in a box that was strapped to the top of the diesel. This ensured that the samplers remained in place throughout the sampling. The sample was collected by drawing between 2 and 4 L/min of mine air through the sampler with the personal sampler pump. The flow rates through the samplers were recorded at the beginning, the middle and the end of the sampling period. Calibration curves for each pump were used to convert these flow rates into volumes of air sampled. The volumes of air sampled by the personal samplers were summed to give the total volume of air sampled. Between 7 and 14 samplers were used to collect a single sample, i.e., the filters from between 7 and 14 samplers were

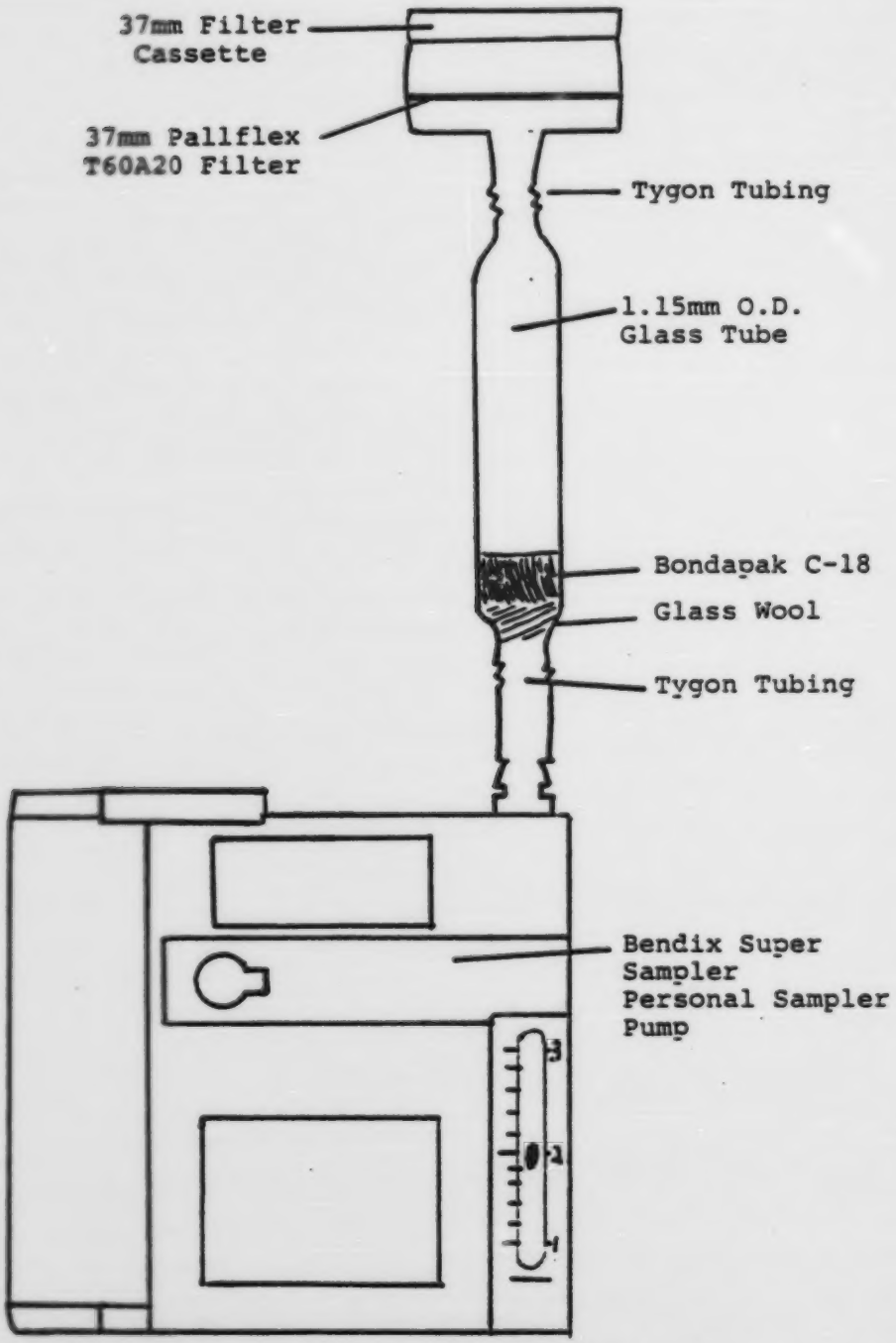

Figure 4 Design of the personal sampler system

combined and analyzed as one filter sample. The resins from the same samplers were also combined to form one personal sampler resin sample.

At the end of the sampling period, the pumps were removed and the filter cassettes were sealed at each end. Upon reaching the laboratory, the filters were weighed and sealed in a polyethylene bag taking care to keep all of the particulate on the inside. The resin tubes were also sealed in sterile polyethylene bags. Both the filters and the resins were stored in a freezer until they could be analyzed.

ANALYTICAL PROCEDURES

Both the PAH and Ames bioassays on the Hi Vol filters were effectively done using the techniques developed in previous studies[2,6]. The only difference in the analysis of the Hi Vol filters arose because each filter sample consisted of several filters. In these cases, each set of Hi Vol filters was extracted in batches of up to 1.5 filters at one time. In most of our earlier work, only one filter was extracted at a time. We do not believe that this change affected the results.

The technique used to extract the 37 mm Palliflex (personal sampler) filter samples differed from that used for the Hi Vol filters in two ways. Only 100 mL, rather than 200 mL volumes of solvent, were used to extract the filter samples with the sonicator. Also, the volume of solvent used in the soxhlet extraction was reduced to 40 mL from the usual 250 mL. These two changes were made because the mass of the filters from the personal samplers was much smaller than that from the Hi Vol samples.

The analysis of the resin samples was done using the same analytical procedures that were employed in all the other PAH and Ames assays. The only difference in the analysis of these samples was in extracting the diesel exhaust components (the organic compounds) from the resin. The extraction involved transfering the resin from the glass or the stainless steel tubes into a 1000 mL beaker. Each resin tube was rinsed with several mL of dichloromethane and the washings were added to the 1000 mL beaker. Then the mixture was extracted three times with 200 mL of dichloromethane. This procedure involved stirring the resin with dichloromethane for 10 min

with a magnetic stirrer, filtering the mixture, and collecting the filtrate (the solvent). Evaporation of the dichloromethane on the rotary evaporator at low temperatures left a concentrate which was stored in a freeezer until it was used in the PAH or Ames assays.

EXPERIMENTAL PLAN

This study determined the amounts of PAHs and mutagens, the sulfur compounds and the respirable combustible dust released by seven different configurations of exhaust treatment devices on Deutz 714 series diesels. The seven exhaust treatment configurations that were tested were:-

1) a Johnson Matthey-Engine Control Systems catalytic trap oxidizer (CTO),

2) a fume diluter,

3) a CTO and a fume diluter in series,

4) the bare A6L-714 Deutz diesel used for tests 1-3,

5) a PTX catalytic convertor,

6) a Corning Diesel Exhaust filter, and

7) the bare F8L-714 Deutz diesel used in the PTX and Corning Diesel Exhaust filter tests.

Eight sets of samples were collected for each engine configuration. Thus, a total of 56 sets of samples were collected for the seven different engine configurations. Each set of samples consisted of a Hi Vol sample at the sampling site, a set of between seven and fourteen personal sampler samples collected in the operator's breathing zone on board the scoop tram and a time-weighted carbon dioxide sample at the sampling site. Each Hi Vol and personal sampler sample consisted of a filter sample and a resin sample collected in the air that had passed through the filter, Figures 3 and 4. Both the filter and resin samples collected at the sampling site and on board the diesel were analyzed for PAHs. Hi Vol filter and resin samples collected at the sampling site were also screened for mutagenic compounds in a multi-strain Ames bioassay. In some cases, additional samples were collected at the sampling site. These samples were analyzed

for sulfur dioxide, sulfate ion, sulfuric acid or respirable combustible dust (RCD).

PAH CONCENTRATIONS IN THE MINE AIR

HI VOL FILTER AND RESIN SAMPLES

The details of the sampling procedure for the Hi Vol filter and resin samples collected at the sampling sites downstream from the diesel are given in Table 1.

The results of the PAH analyses on the Hi Vol filter and resin samples for each configuration of exhaust treatment device are presented in Tables 2-7. The average PAH concentrations on the filter and resin samples for each exhaust treatment system are also given in these Tables.

An analysis of the data in Tables 2-7 shows that most of the PAHs that were collected by the Hi Vol sampling system are on the filter. In fact, ten out of the twelve resin samples collected behind the Pallflex filters in the Hi Vol samplers do not contain significant amounts of PAHs. For example, if the two exceptions are ommitted, three PAHs were present in detectable amounts on only two of the remaining ten resin samples and there were two or fewer PAHs on the resin in all 8 of the remaining resin samples. By comparison, the filter samples contained between 9 and 12 PAHs in detectable amounts. The same conclusion is reached when the results are examined from another point of view. The Total PAHs on the resin average less than 10% of the PAHs on the filters and 67% of the resin samples have less than 5% of the PAHs found on the filter.

Although both analyses of the data suggest that the PAHs are almost completely on the Hi Vol filter rather than on the resin, significant amounts of PAHs were found on the resin samples in two instances. One resin sample has 6 PAHs and the other had 10 PAHs. In both these cases, there are more PAHs on the resin than on the filter. These results are in direct contrast to those found in ten other samples and may, therefore, be in error. In fact, this seems entirely possible because the higher

TABLE 1. Sampling conditions for Hi Vol PAH samples in Tables 2-7.

Sample Number*	Exhaust Treatment Device	Sampling Time (min)	Number of Filters	Volume of Air (m^3)	%CO2 at Sampling Site
F 016R	none	195	3	253.21	0.105
F 28L	none	234	5	295.95	0.108
R 016T	none	340		7.85	0.105
R 014T	none	354		7.12	0.095
F 020,21R	CTO	408	5	537.32	0.12
F 022R	CTO	403	5	515.81	0.12
R 020T	CTO	810		16.46	0.12
R 028T	CTO	766		15.42	0.105
F 030R	FD	142	3	183.21	0.127
F 130AR	FD	204	5	260.39	0.127
F 25R	FD	231	5	290.98	0.135
R 130BT	FD	692		13.93	0.127
R 130AR	FD	204		4.06	0.127
R 25R	FD	235		4.67	0.135
F 10R	CTO & FD	362	5	466.93	0.153
F 13L	CTO & FD	329	3	499.06	0.146
R 10R	CTO & FD	362		7.20	0.153
F 11?R	none	212	3	299.18	0.166
F 119AR	none	168	3	215.89	0.176
R 11?T	none	424		8.53	0.166
F MR?R	Corning	301	1	417.04	0.147
F 124,25R	Corning	382		485.07	0.202
R MR?R	Corning	602		12.12	0.147
R 124,24R	Corning	761		15.52	0.202
R To5T	Corning	906		18.24	0.162
F 111L	PTX	138	2	174.58	
F 112R	PTX	175	3	257.59	

* If F is the first letter in the sample number, the sample is a filter. If the first letter is an R, it is a resin sample.

Table 2. PAH concentrations from Hi Vol filter and resin samples downstream from an A6L-714 Deutz diesel with no exhaust treatment device.

	PAH concentrations in ng/m3 of air sampled					
SAMPLE	FILTER F28L	FILTER D16R	RESIN D16T	RESIN D14T	AVERAGE FILTER	AVERAGE RESIN
PYRENE	201.31	241.87	0.00	0.00	221.59	0.00
FLUORANTHENE	2.96	11.08	0.00	0.00	7.02	0.00
BENZO(a)ANTHRACENE	11.91	N.A.	0.00	0.00	11.91	0.00
BENZO(e)PYRENE	86.07	95.69	0.00	0.00	90.88	0.00
PERYLENE	1.21	0.52	0.00	0.83	0.87	0.42
3-METHYLCHOLANTHRENE	0.00	0.00	0.00	0.00	0.00	0.00
BENZO(k)FLUORANTHENE	5.96	2.79	0.00	0.00	4.37	0.00
BENZO(a)PYRENE	6.36	5.27	0.00	0.00	5.81	0.00
BENZO(ghi)PERYLENE	21.71	7.95	0.00	0.00	14.83	0.00
DIBENZO(def,mno)CHRYSENE	1.38	0.00	0.00	0.00	0.69	0.00
DIBENZO(a,h)ANTHRACENE	0.00	0.00	0.00	0.00	0.00	0.00
NAPHTHO(1,2,3,4,def)CHRYSENE	4.27	8.23	0.00	0.00	6.25	0.00
BENZO(rst)PENTAPHENE	1.94	1.80	0.00	0.00	1.87	0.00
TOTAL PAHs	345.09	**	0.00	0.83	366.10*	0.42
TOTAL PAHs-PYRENE	143.78	**	0.00	0.83	144.51*	0.42
CARCINOGENS	46.19	**	0.00	0.00	40.68*	0.00

N.A. - Not available.
* Calculated from the average concentrations for each PAH.
** These values have not been reported because the B(a)A concentration is not available.

Table 3. PAH concentrations from Hi Vol filter and resin samples collected downstream from an A6L-714 Deutz diesel with a Johnson-Matthey CTO.

	PAH concentrations in ng/m3 of air sampled					
SAMPLE	FILTER D20-21R	FILTER D22R	RESIN D20T	RESIN D28T	AVERAGE FILTER	AVERAGE RESIN
PYRENE	33.22*	52.25	0.00	0.00	52.25*	0.00
FLUORANTHENE	2.77	2.18	0.00	0.00	2.48	0.00
BENZO(a)ANTHRACENE	0.00	1.39	10.69	0.00	0.69	5.35
BENZO(e)PYRENE	30.55	14.24	0.00	0.00	22.40	0.00
PERYLENE	0.21	0.07	0.00	0.00	0.14	0.00
3-METHYLCHOLANTHRENE	2.72	0.00	0.00	0.00	1.36	0.00
BENZO(k)FLUORANTHENE	0.00	0.36	0.00	0.00	0.18	0.00
BENZO(a)PYRENE	2.31	0.24	0.00	0.00	1.27	0.00
BENZO(ghi)PERYLENE	8.53	1.16	0.00	0.00	4.84	0.00
DIBENZO(def,mno)CHRYSENE	0.00	0.04	0.00	0.00	0.02	0.00
DIBENZO(a,h)ANTHRACENE	1.99	0.00	0.00	0.00	0.99	0.00
NAPHTHO(1,2,3,4,def)CHRYSENE	1.47	2.61	0.00	0.00	2.04	0.00
BENZO(rst)PENTAPHENE	0.47	0.00	0.00	0.00	0.24	0.00
TOTAL PAHs	84.24*	74.54	10.69	0.00	88.90**	5.35
TOTAL PAHs-PYRENE	51.02	22.29	10.69	0.00	36.65	5.35
CARCINOGENS	17.49	5.40	10.69	0.00	11.44	5.35

* The pyrene concentration reported is low.
** The incorrect pyrene concentration was not used in calculating the average.

Table 4. PAH concentrations from Hi Vol filter and resin samples collected downstream from an A6L-714 Deutz diesel with a fume diluter.

	PAH concantrations in ng/m3 of air sampled							
	FILTER J300R	FILTER J30AR	FILTER F3R	RESIN J300T	RESIN J30AR	RESIN F3R	AVERAGE FILTER	AVERAGE RESIN
PYRENE	212.85	173.33	224.48	0.00	490.49	0.00	203.55	163.50
FLUORANTHENE	5.33	5.89	13.29	2.93	22.56	0.00	8.17	8.50
BENZO(a)ANTHRACENE	22.68	28.03	15.52	21.52	74.35	18.77	22.08	38.21
BENZO(e)PYRENE	55.31	66.18	60.68	49.35	258.64	0.00	60.72	102.67
PERYLENE	0.81	0.88	1.01	0.00	0.00	0.00	0.90	0.00
3-METHYLCHOLANTHRENE	8.01	0.00	0.00	0.00	0.00	0.00	2.67	0.00
BENZO(k)FLUORANTHENE	0.00	4.09	3.00	0.00	0.00	0.00	2.36	0.00
BENZO(a)PYRENE	2.11	5.22	3.90	0.00	2.91	0.00	3.74	0.97
BENZO(ghi)PERYLENE	0.00	12.89	16.20	0.00	0.00	0.00	9.69	0.00
DIBENZO(daf,ano)CHRYSENE	1.43	0.91	0.99	0.00	0.00	0.00	1.11	0.00
DIBENZO(a,h)ANTHRACENE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NAPHTHO(1,2,3,4,def)CHRYSENE	18.03	2.27	9.01	0.00	12.50	0.00	9.77	4.17
BENZO(rst)PENTAPHENE	0.00	1.01	1.05	0.00	0.00	0.00	0.69	0.00
TOTAL PAHs	326.55	300.69	349.12	73.80	861.44	18.77	325.45	318.01
TOTAL PAHs-PYRENE	113.70	127.36	124.64	73.80	370.96	18.77	121.90	154.51
CARCINOGENS	50.83	49.41	45.68	21.52	89.75	18.77	48.64	43.35

Table 5. PAH concentrations from Hi Vol filter and resin samples collected downstream from an AGL-714 Deutz diesel fitted with a CTO and a fume diluter.

	PAH concentrations in ng/m3 of air sampled				
	FILTER FIOR	FILTER FISI	RESIN FIOR	AVERAGE FILTER	AVERAGE RESIN
PYRENE	54.24	35.63	0.00	44.93	0.00
FLUORANTHENE	3.65	3.96	0.00	3.79	0.00
BENZO(a)ANTHRACENE	1.56	1.43	0.00	1.50	0.00
BENZO(e)PYRENE	27.41	17.95	0.00	22.68	0.00
PERYLENE	0.08	2.68	0.61	1.38	0.61
3-METHYLCHOLANTHRENE	0.00	1.47	0.00	0.73	0.00
BENZO(k)FLUORANTHENE	0.60	0.45	0.00	0.53	0.00
BENZO(a)PYRENE	0.49	0.14	0.00	0.32	0.00
BENZO(ghi)PERYLENE	0.36	1.19	1.50	0.78	1.50	
DIBENZO(a,e,f,mno)CHRYSENE	0.05	0.00	0.00	0.02	0.00
DIBENZO(a,h)ANTHRACENE	0.00	0.00	0.00	0.00	0.00
NAPHTHO(1,2,3,4,def)CHRYSENE	8.36	0.00	0.00	4.18	0.00
BENZO(rst)PENTAPHENE	0.00	0.37	0.00	0.18	0.00
TOTAL PAHs	96.76	65.27	2.11	81.02	2.11
TOTAL PAHs-PYRENE	42.53	29.63	2.11	36.08	2.11
CARCINOGENS	10.76	1.60	1.50	7.68	1.50

Table 6. PAH concentrations from Hi Vol filter and resin samples collected downstream from an F8L-714 Deutz diesel with no exhaust treatment device.

SAMPLE	PAH concentrations in ng/m3 of air sampled				
	FILTER J17R	FILTER J19DR	RESIN J17T	AVERAGE FILTER	AVERAGE RESIN
PYRENE	207.91*	84.84*	0.00	146.38*	0.00
FLUORANTHENE	26.12	2.32	7.04	14.22	7.04
BENZO(a)ANTHRACENE	39.78	21.95	8.23	30.86	8.23
BENZO(e)PYRENE	119.65	79.96	0.00	99.80	0.00
PERYLENE	1.30	6.81	0.00	4.06	0.00
3-METHYLCHOLANTHRENE	0.00	3.26	0.00	1.63	0.00
BENZO(k)FLUORANTHENE	7.44	20.40	0.00	13.92	0.00
BENZO(a)PYRENE	4.12	19.36	0.00	11.74	0.00
BENZO(ghi)PERYLENE	28.31	60.97	0.00	44.64	0.00
DIBENZO(def,mno)CHRYSENE	2.03	0.00	0.00	1.02	0.00
DIBENZO(a,h)ANTHRACENE	0.00	4.96	0.00	2.48	0.00
NAPHTHO(1,2,3,4,def)CHRYSENE	13.30	33.77	0.00	23.53	0.00
BENZO(rst)PENTAPHENE	1.12	12.77	0.00	6.95	0.00
TOTAL PAHs	451.07*	351.38*	15.26	401.23*	15.26
TOTAL PAHs-PYRENE	243.16	266.54	15.26	254.85	15.26
CARCINOGENS	86.62	157.05	8.23	121.83	8.23

* The pyrene concentration reported is low.

Table 7a. PAH concentrations from Hi Vol filter and resin samples collected downstream from an F8L-714 Deutz diesel fitted with a Corning Diesel Exhaust Filter.

	PAH concentrations in ng/m3 of air sampled						
SAMPLE	FILTER MR7R	FILTER J24,25R	RESIN MR7T	RESIN J24,25R	RESIN JU6T	AVERAGE FILTER	AVERAGE RESIN
PYRENE	38.11	25.68*	300.45	0.00	0.00	38.11**	100.15
FLUORANTHENE	0.21	7.28	5.42	2.95	1.89	3.74	3.41
BENZO(a)ANTHRACENE	5.80	1.18	111.33	6.24	8.53	3.49	42.03
BENZO(a)PYRENE	23.95	20.86	108.87	0.00	0.00	22.41	36.29
PERYLENE	0.54	0.23	2.01	0.00	0.00	0.39	0.67
3-METHYLCHOLANTHRENE	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BENZO(k)FLUORANTHENE	3.89	1.99	16.10	0.00	0.00	2.94	5.37
BENZO(a)PYRENE	2.84	1.58	4.46	0.00	0.00	2.21	1.49
BENZO(ghi)PERYLENE	6.29	4.45	61.07	0.00	3.41	5.37	21.16
DIBENZO(def,mno)CHRYSENE	0.51	0.33	0.00	0.00	0.00	0.42	0.00
DIBENZO(a,h)ANTHRACENE	2.27	0.00	149.86	0.00	0.00	1.13	49.95
NAPHTHO(1,2,3,4,def)CHRYSENE	8.73	3.24	16.85	0.00	0.00	5.98	5.61
BENZO(rst)PENTAPHENE	2.99	0.38	0.00	0.00	0.00	1.69	0.00
TOTAL PAHs	96.13	65.20*	776.59	9.19	13.84	87.88**	263.08
TOTAL PAHs-PYRENE	58.01	41.51	476.95	9.19	13.84	49.76	169.98
CARCINOGENS	28.91	10.82	343.65	6.24	10.94	19.87	120.24

* The pyrene concentration reported is low.

** The incorrect pyrene concentration was not used in calculating the average.

Table 7b. PAH concentrations from Hi Vol filter samples collected downstream from an F8L-714 Deutz dieles fitted with a PTX catalyst.

SAMPLE	PAH concentrations in ng/m3 of air sampled FILTER J11L	FILTER J12R	AVERAGE FILTER
PYRENE	228.46	130.16*	228.46**
FLUORANTHENE	5.16	4.76	4.96
BENZO(a)ANTHRACENE	3.85	0.00	1.92
BENZO(e)PYRENE	57.07	30.16	43.62
PERYLENE	0.47	0.66	0.56
3-METHYLCHOLANTHRENE	0.00	0.00	0.00
BENZO(k)FLUORANTHENE	5.00	3.90	4.45
BENZO(a)PYRENE	2.28	2.06	2.17
BENZO(ghi)PERYLENE	17.54	25.70	21.62
DIBENZO(def,mno)CHRYSENE	1.23	1.92	1.58
DIBENZO(a,h)ANTHRACENE	15.22	14.45	14.83
NAPHTHO(1,2,3,4,def)CHRYSENE	2.54	15.25	8.90
BENZO(rst)PENTAPHENE	2.91	1.48	2.19
TOTAL PAHs	341.73	230.49*	335.26**
TOTAL PAHs-PYRENE	113.27	100.33	106.80
CARCINOGENS	44.34	58.93	51.63

* The pyrene concentration reported is low.

** The incorrect pyrene concentration was not used in calculating the average.

concentrations of PAHs on the resin were only found in one of three samples collected when the Corning filter was on the diesel and in one of three samples collected downstream from the diesel fitted with the fume diluter. Thus, the results quoted for the two samples where more PAHs were found on the resin seem suspect and it appears that only small amounts of the PAHs collected by the Hi Vol sampler are collected on the resin.

Although only small amounts of PAHs are found on the resin Hi Vol sample, it is important to note that significant amounts of the lower molecular weight PAHs are found on the resin. In fact, the lower molecular weight and presumably more volatile PAHs, fluoranthene, pyrene, benzo(a)anthracene and benzo(e)pyrene account for over 60% of the PAHs found in the resin samples. This demonstrates that these PAHs are not retained on the Hi Vol filter quantitatively. This is confirmed because the concentrations of these more volatile PAHs in the resin sample equal or exceed the concentrations of these PAHs on the corresponding Hi Vol filter samples. This is consistent with the results of several other studies which indicate that the low molecular weight, more volatile PAHs are not captured quantitatively on Hi Vol filters.[5,7-11]

A COMPARISON OF THE PAHs AT THE SAMPLING SITE WITH THE VARIOUS EXHAUST TREATMENT DEVICES

The data presented in Tables 2-7 is displayed in a more useful form, from an engineering point of view, in Tables 8-15. These Tables use the average PAH concentrations found on the Hi Vol filters collected downstream from the diesel to demonstrate the effect of each type of exhaust treatment device on the PAH concentrations in the air at the sampling site.

Tables 8-12 compare the PAH concentrations in the mine air downstream from the A6L-714 Deutz diesel working in a stope on the 2250 foot level of Falconbridge Limited's Strathcona mine. The data in Table 8 shows that the Johnson Matthey-Engine Control Systems CTO reduces the PAH concentrations in the mine air significantly. In fact, the CTO reduces the Total PAHs, the Total-Pyrene and the Total Carcinogens to approximately 25% of the levels found for the bare engine. Moreover, all of the PAHs are significantly lower downstream from the diesel when the CTO is used, i.e.,

Table 8. A comparison of the PAH concentrations found downstream from an A6L-714 Deutz diesel with a) a Johnson-Matthey-Engine Control Systems CTO and b) no exhaust treatment device.

SAMPLE	PAH concentrations in ng/m3 of air sampled: AVERAGE CTO HI VOL FILTER	AVERAGE BARE ENGINE HI VOL FILTER	CTO / BARE ENGINE
PYRENE	52.25	221.58	0.24
FLUORANTHENE	2.48	7.02	0.35
BENZO(a)ANTHRACENE	0.69	11.91	0.06
BENZO(e)PYRENE	22.40	90.88	0.25
PERYLENE	0.14	0.87	0.16
3-METHYLCHOLANTHRENE	1.36	0.00	-
BENZO(k)FLUORANTHENE	0.18	4.37	0.04
BENZO(a)PYRENE	1.27	5.81	0.22
BENZO(ghi)PERYLENE	4.84	14.83	0.33
DIBENZO(def,mno)CHRYSENE	0.02	0.69	0.03
DIBENZO(a,h)ANTHRACENE	0.99	0.00	-
NAPHTHO(1,2,3,4,def)CHRYSENE	2.04	6.25	0.33
BENZO(rst)PENTAPHENE	0.24	1.87	0.13
TOTAL PAHs	88.90	366.10	0.24
TOTAL PAHs-PYRENE	36.65	144.51	0.25
CARCINOGENS	11.44	40.68	0.28

the PAH concentrations downstream from the CTO range from only 3 to 35% of the concentrations found downstream from the bare engine. Thus, the CTO appears to be very effective in reducing the PAHs in the mine air downstream from the diesel.

The fume diluter, on the other hand, does not affect the PAH concentrations at the end of the drift. The results of three different experiments, Table 9, show that the concentrations of the individual PAHs at the sampling site are between 37% and 185% of those found with the bare engine. Moreover, the Total PAHs, the Total-Pyrene and the Total Carcinogens range from 84% to 120% of those found with the bare engine and the average of these three ratios is 0.98. This clearly indicates that the fume diluter does not alter the PAH concentrations in the air at the sampling site. This is to be expected. The fume diluter is designed to throw or blow the exhaust away from the scoop tram operator. Thus, while the fume diluter may be effective for the operator, it does not reduce the exposure of others working downstream from the diesel.

The PAH concentrations downstream from the diesel fitted with a CTO and a fume diluter, Table 10, are, as expected, significantly lower than those found downstream from the bare engine. Again, the Total PAHs, the Total-Pyrene, and the Total Carcinogens range from 19% to 25% of the corresponding totals for the bare engine. Also, all but one of the PAHs are significantly lower when the CTO and fume diluter are used. In fact, the individual PAHs downstream from the diesel fitted with the CTO and fume diluter range from 4% to 67% of those found for the bare engine. The only exception is perylene which is 1.6 times more concentrated in the CTO-fume diluter test. However, this PAH is present in very low concentrations and moreover, is only one out of the twelve PAHs which were analyzed. Thus, the higher perylene concentration with the CTO-fume diluter may be due to experimental error. In any case, the slightly higher concentration of perylene in the CTO-fume diluter exhaust does not affect the final conclusion, i.e., that the CTO-fume diluter combination is effective in removing PAHs from the mine air.

The results in Table 11 demonstrate that the CTO, not the fume diluter, is responsible for reducing the PAHs at the sampling site. The ratio of

Table 9. A comparison of the PAH concentrations found downstream from an A6L-714 Deutz diesel with a) a fume diluter and b) no exhaust treatment device.

SAMPLE	PAH concentrations in ng/m3 of air sampled		
	AVERAGE FUME DILUTER HI VOL FILTER	AVERAGE BARE ENGINE HI VOL FILTER	FUME DILUTER / BARE ENGINE
PYRENE	203.55	221.58	0.92
FLUORANTHENE	8.17	7.02	1.16
BENZO(a)ANTHRACENE	22.08	11.91	1.85
BENZO(e)PYRENE	60.72	90.88	0.67
PERYLENE	0.90	0.87	1.04
3-METHYLCHOLANTHRENE	2.67	0.00	-
BENZO(k)FLUORANTHENE	2.36	4.37	0.54
BENZO(a)PYRENE	3.74	5.81	0.64
BENZO(ghi)PERYLENE	9.69	14.83	0.65
DIBENZO(def,mno)CHRYSENE	1.11	0.69	1.60
DIBENZO(a,h)ANTHRACENE	0.00	0.00	-
NAPHTHO(1,2,3,4,def)CHRYSENE	9.77	6.25	1.56
BENZO(rst)PENTAPHENE	0.69	1.87	0.37
TOTAL PAHs	325.45	366.10	0.89
TOTAL PAHs-PYRENE	121.90	144.51	0.84
CARCINOGENS	48.64	40.68	1.20

Table 10. A comparison of the PAH concentrations found downstream from an A6L-714 Deutz diesel with a) a CTO and a fume diluter and b) no exhaust treatment device.

SAMPLE	PAH concentrations in ng/m3 of air sampled: AVERAGE FD & CTO HI VOL FILTER	AVERAGE BARE ENGINE HI VOL FILTER	FD & CTO / BARE ENGINE
PYRENE	44.93	221.58	0.20
FLUORANTHENE	3.79	7.02	0.54
BENZO(a)ANTHRACENE	1.50	11.91	0.13
BENZO(e)PYRENE	22.68	90.88	0.25
PERYLENE	1.38	0.87	1.59
3-METHYLCHOLANTHRENE	0.73	0.00	-
BENZO(k)FLUORANTHENE	0.53	4.37	0.12
BENZO(a)PYRENE	0.32	5.81	0.05
BENZO(ghi)PERYLENE	0.78	14.83	0.05
DIBENZO(def,mno)CHRYSENE	0.02	0.69	0.04
DIBENZO(a,h)ANTHRACENE	0.00	0.00	-
NAPHTHO(1,2,3,4,def)CHRYSENE	4.18	6.25	0.67
BENZO(rst)PENTAPHENE	0.18	1.87	0.10
TOTAL PAHs	81.02	366.10	0.22
TOTAL PAHs-PYRENE	36.08	144.51	0.25
CARCINOGENS	7.68	40.68	0.19

Table 11. A comparison of the PAH concentrations found downstream from an A6L-714 Deutz diesel with a) a CTO and a fume diluter and b) a fume diluter only.

SAMPLE	PAH concentrations in ng/m3 of air sampled: AVERAGE FD & CTO HI VOL FILTER	AVERAGE FD HI VOL FILTER	FD & CTO / FD
PYRENE	44.93	203.55	0.22
FLUORANTHENE	3.79	8.17	0.46
BENZO(a)ANTHRACENE	1.50	22.08	0.07
BENZO(e)PYRENE	22.68	60.72	0.37
PERYLENE	1.38	0.90	1.53
3-METHYLCHOLANTHRENE	0.73	2.67	0.27
BENZO(k)FLUORANTHENE	0.53	2.36	0.22
BENZO(a)PYRENE	0.32	3.74	0.08
BENZO(ghi)PERYLENE	0.78	9.69	0.08
DIBENZO(def,mno)CHRYSENE	0.02	1.11	0.02
DIBENZO(a,h)ANTHRACENE	0.00	0.00	-
NAPHTHO(1,2,3,4,def)CHRYSENE	4.18	9.77	0.43
BENZO(rst)PENTAPHENE	0.18	0.69	0.27
TOTAL PAHs	81.02	325.45	0.25
TOTAL PAHs-PYRENE	36.08	121.90	0.30
CARCINOGENS	7.68	48.64	0.16

the PAHs downstream from the diesel fitted with a CTO and fume diluter are much lower than those downstream from the diesel with the fume diluter. In fact, the concentration of all but one of the PAHs is significantly lower at the sampling site when the CTO and fume diluter are being used, i.e., the individual PAHs range from 2 to 46% of those found with the fume diluter alone. Only perylene is slightly higher when the CTO and fume diluter is used and this result is probably due to an error in in the analysis of one of the samples, i.e., one of the CTO-fume diluter samples had an unusually high concentration of perylene. The ratios for the Total PAHs, the Total-Pyrene and the Total Carcinogens for the (CTO-fume diluter/fume diluter) are virtually identical to the corresponding ratios for the CTO/bare engine, i.e., the ratios range from 0.30 to 0.16 with an average of 0.24 for the (CTO + fume diluter/fume diluter) and from 0.28 to 0.24 with an average of 0.26 for the CTO/bare engine. Since these ratios are almost identical, one is forced to conclude that the CTO and not the fume diluter is responsible for lowering the PAHs in the air at the sampling site.

The results presented in Table 12 confirm that the fume diluter does not affect the PAH concentrations in the air at the sampling site. The (CTO-fume diluter/CTO) ratios for the Total PAHs, the Total-Pyrene and the Total Carcinogens range from 0.67 to 0.98 with an average value of 0.85. These ratios will only be close to 1.0 if the fume diluter has little or no effect on the PAHs at the sampling site.

The results obtained with a PTX catalytic convertor and a Corning Diesel Exhaust filter on a F8L-714 Deutz diesel on the 1400 foot level at Inco Metals Company's Little Stobie mine are given in Tables 13-15. The data in Table 13 indicates that the PTX has a small beneficial effect on the PAH levels downstream from the diesel. Although the levels of the individual PAHs found downstream from the engine with the PTX catalyst range from 14% to 600% of those found with the bare engine, the Total-Pyrene and the Total Carcinogens found when the PTX is used are only 0.42 or 42% of the corresponding totals from the bare engine experiment. Thus, the PTX catalyst seems to have a small, beneficial effect on the air downstream from a diesel. However, the effect of the PTX catalyst is opposite to that found in a previous study. Mogan and coworkers reported that the PAHs were 33% higher when the PTX catalyst was used. In addition, Ames bioassays of the

Table 12. A comparison of the PAH concentrations found downstream from an A6L-714 Dautz diesel with a) a CTO and a fume diluter and b) a CTO only.

SAMPLE	PAH concentrations in ng/m3 of air sampled AVERAGE FD & CTO HI VOL FILTER	AVERAGE CTO HI VOL FILTER	FD & CTO / CTO
PYRENE	44.93	52.25	0.86
FLUORANTHENE	3.79	2.48	1.53
BENZO(a)ANTHRACENE	1.50	0.69	2.16
BENZO(e)PYRENE	22.68	22.40	1.01
PERYLENE	1.38	0.14	9.82
3-METHYLCHOLANTHRENE	0.73	1.36	0.54
BENZO(k)FLUORANTHENE	0.53	0.18	2.95
BENZO(a)PYRENE	0.32	1.27	0.25
BENZO(ghi)PERYLENE	0.78	4.84	0.16
DIBENZO(def,mno)CHRYSENE	0.02	0.02	1.00
DIBENZO(a,h)ANTHRACENE	0.00	0.99	0.00
NAPHTHO(1,2,3,4,def)CHRYSENE	4.18	2.04	2.05
BENZO(rst)PENTAPHENE	0.18	0.24	0.75
TOTAL PAHs	81.02	88.90	0.91
TOTAL PAHs-PYRENE	36.08	36.65	0.98
CARCINOGENS	7.68	11.44	0.67

Table 13. A comparison of the PAH concentrations found downstream from an F8L-714 Deutz diesel with a) PTX catalytic converter and b) with no exhaust treatment device.

SAMPLE	PAH concentrations in ng/m3 of air sampled: AVERAGE PTX HI VOL FILTER	AVERAGE BARE ENGINE HI VOL FILTER	PTX / BARE ENGINE
PYRENE	228.46	146.38*	1.56**
FLUORANTHENE	4.96	14.22	0.35
BENZO(a)ANTHRACENE	1.92	30.86	0.06
BENZO(e)PYRENE	43.62	99.80	0.44
PERYLENE	0.56	4.06	0.14
3-METHYLCHOLANTHRENE	0.00	1.63	0.00
BENZO(k)FLUORANTHENE	4.45	13.92	0.32
BENZO(a)PYRENE	2.17	11.74	0.18
BENZO(ghi)PERYLENE	21.62	44.64	0.48
DIBENZO(def,mno)CHRYSENE	1.52	1.02	1.49
DIBENZO(a,h)ANTHRACENE	14.83	2.48	5.98
NAPHTHO(1,2,3,4,def)CHRYSENE	8.90	23.53	0.38
BENZO(rst)PENTAPHENE	2.19	6.95	0.32
TOTAL PAHs	335.26	401.23*	0.84**
TOTAL PAHs-PYRENE	106.80	254.85	0.42
CARCINOGENS	51.63	121.83	0.42

* The pyrene concentration reported is low.
** The ratio reported is high because the pyrene concentration for the bare engine is low.

exhaust from Deutz diesels operating with and without a PTX catalyst indicated that the PTX catalyst increased the mutagens in the exhaust approximately eleven times.[12]

Table 14 shows the effect of adding a Corning Diesel Exhaust filter to the exhaust train of a diesel. The results indicate that this filter is also efficient at reducing the PAH concentrations in the air downstream from the diesel. In fact, all of the PAH concentrations are significantly lower in the mine air when the Corning filter is used. The individual PAHs downstream from the engine with the Corning filter range from 10 to 46% of those found for the bare engine. In addition, the Total PAHs, Total-Pyrene and Total Carcinogens for the Corning filter are only 16-22% of the corresponding values for the bare engine.

The results in Table 15 show that the Corning Diesel Exhaust filter is much better than the PTX catalyst in removing the PAHs from the mine air. All but two of the PAHs, benzo(a)pyrene and benzo(a)anthracene, are in significantly lower concentrations in the air downstream from the diesel fitted with the Corning filter. Of the two PAHs that are not reduced by the Corning filter, the concentration of the benzo(a)pyrene is the same for both exhaust treatment systems and the benzo(a)anthracene is only 1.8 times more concentrated when the Corning filter is used. In addition, the Total PAHs, the Total-Pyrene and the Total Carcinogens in the air downstream from the engine with the Corning filter range from 26-47% (an average of 37%) of those in the air downstream from an engine fitted with a PTX catalyst. Thus, the overall effect of the Corning filter is clear. It is clearly superior to the PTX for removing the PAHs from the mine air.

In summary, the fume diluter does not affect the PAH concentrations in the air downstream from a diesel significantly. Although the PTX catalyst appears to reduce the PAHs in the air at the sampling site slightly, this conclusion is suspect. A previous test indicated that the PTX catalyst caused a 33% increase in the PAH concentrations. Both the CTO and the Corning filter, on the other hand, reduce the PAHs in the mine air markedly. Although the CTO and the Corning filter seem to have almost identical effects on the PAHs in the mine air, the Corning filter would appear to be the best exhaust treatment device from an operating point of view. The

Table 14. A comparison of the PAH concentrations found downstream from an F8L-714 Deutz diesel with a) Corning filter and b) with no exhaust treatment device.

SAMPLE	PAH concentrations in ng/m3 of air sampled: AVERAGE CORNING HI VOL FILTER	AVERAGE BARE ENGINE HI VOL FILTER	CORNING / BARE ENGINE
PYRENE	38.11	146.38*	0.26
FLUORANTHENE	3.74	14.22	0.26
BENZO(a)ANTHRACENE	3.49	30.86	0.11
BENZO(e)PYRENE	22.41	99.80	0.22
PERYLENE	0.39	4.06	0.10
3-METHYLCHOLANTHRENE	0.00	1.63	0.00
BENZO(k)FLUORANTHENE	2.94	13.92	0.21
BENZO(a)PYRENE	2.21	11.74	0.19
BENZO(ghi)PERYLENE	5.37	44.64	0.12
DIBENZO(def,mno)CHRYSENE	0.42	1.02	0.41
DIBENZO(a,h)ANTHRACENE	1.13	2.48	0.46
NAPHTHO(1,2,3,4,def)CHRYSENE	5.98	23.53	0.25
BENZO(rst)PENTAPHENE	1.69	6.95	0.24
TOTAL PAHs	87.88	401.23*	0.22**
TOTAL PAHs-PYRENE	49.76	254.85	0.20
CARCINOGENS	19.87	121.83	0.16

* The pyrene concentration reported is low.

** The ratio reported is high because the pyrene concentration for the bare engine is low.

Table 15. A comparison of the PAH concentrations found downstream from an F8L-714 Deutz diesel with a) a Corning filter and b) a PTX catalyst.

SAMPLE	PAH concentrations in ng/m3 of air sampled: AVERAGE CORNING HI VOL FILTER	AVERAGE PTX HI VOL FILTER	CORNING / PTX
PYRENE	38.11	228.46	0.17
FLUORANTHENE	3.74	4.96	0.75
BENZO(a)ANTHRACENE	3.49	1.92	1.81
BENZO(e)PYRENE	22.41	43.62	0.51
PERYLENE	0.39	0.56	0.70
3-METHYLCHOLANTHRENE	0.00	0.00	-
BENZO(k)FLUORANTHENE	2.94	4.45	0.66
BENZO(a)PYRENE	2.21	2.17	1.02
BENZO(ghi)PERYLENE	5.37	21.62	0.25
DIBENZO(def,mno)CHRYSENE	0.42	1.58	0.27
DIBENZO(a,h)ANTHRACENE	1.13	14.83	0.08
NAPHTHO(1,2,3,4,def)CHRYSENE	5.98	8.90	0.67
BENZO(rst)PENTAPHENE	1.69	2.19	0.77
TOTAL PAHs	87.88	335.26	0.26
TOTAL PAHs-PYRENE	49.76	106.80	0.47
CARCINOGENS	19.87	51.63	0.38

CTO used in these tests developed a large back pressure after only a few hours of operation. This makes it impossible to use the CTO from an operating point of view. The second problem is that larger amounts of sulfate were found in the air downstream from the CTO. If this is indicative of an increase in sulfuric acid in the air downstream from the diesel, the CTO is again less attractive. Both of these points will be discussed in more detail below.

PERSONAL SAMPLER FILTER AND RESIN SAMPLES

The details of the sampling done on board the diesel with personal samplers (see Figure 4) are given in Table 16. The PAH concentrations found in the air in the breathing zone of the scoop tram operator when different exhaust treatment devices are used, are presented in Tables 17-21.

The PAH concentrations calculated from the analysis of both the filter and XAD-2 resin samples collected in the breathing zone of the operator of an A6L-714 Deutz diesel operating on a controlled LHD cycle with no exhaust treatment device, i.e., a bare engine, at Falconbridge's Strathcona mine, are given in Table 17. An examination of the PAH concentrations found in five different Pallflex filter and XAD-2 resin samples shows that most of the PAHs are on the filter portion rather than the resin portion of these samples.

This conclusion is supported by the average PAH concentrations for the filter and resin samples (see the last two columns of Table 17). The totals at the bottom of these columns show that the Total PAHs on the average resin sample only account for 16% of the PAHs in the average sample. A similar comparison for the Total-pyrene and for the Total Carcinogens indicates that only 21% and 3%, respectively, of the PAHs are on the resin portion of the on board samples.

The results also show, with one exception, that only the more volatile PAHs, pyrene, fluoranthene, benzo(a)anthracene and benzo(e)pyrene are found in detectable quantities in the resin samples. The one exception was when some benzo(k)fluoranthene was found in one of the five resin samples that were analyzed. Thus, the distribution of the PAHs in the filter and resin

Table 16. Sampling conditions for the samples collected on board the diesel.

SAMPLE	LOCATION	EXHAUST TREATMENT DEVICE	VOLUME OF AIR (m3)	EXTRACT WEIGHT (g)	NUMBER OF SAMPLERS USED
Filter S16	Falconbridge	None	0.93	0.01211	5
Filter D20	Falconbridge	None	3.82	0.01771	8
Filter N22	Falconbridge	None	3.28	0.00352	4
Filter D6	Falconbridge	None	3.73	0.00271	14
Filter D13	Falconbridge	None	5.12	0.00400	14
Filter D14	Falconbridge	None	5.00	0.00533	14
Filter F28	Falconbridge	None	4.25	0.00608	13
Resin D13,14	Falconbridge	None	10.12	0.01661	26
Resin D15,16	Falconbridge	None	11.47	0.00759	28
Resin D20	Falconbridge	None	3.82	0.00255	8
Resin N22	Falconbridge	None	3.20	0.01745	14
Resin D6	Falconbridge	None	3.73	0.00415	13
Filter F1	Falconbridge	FD	11.98	0.01701	12
Filter F3	Falconbridge	FD	10.30	0.01896	12
Filter D20	Falconbridge	CTD	7.31	0.01459	14
Filter D22	Falconbridge	CTD	4.02	0.02290	13
Filter F10	Falconbridge	FD & CTD	9.12	0.02598	6
Filter F13	Falconbridge	FD & CTD	10.15	0.00496	6
Filter J23	Inco	Corning	6.87	0.00830	12
Filter J23	Inco	Corning	6.43	0.00833	12
Filter J19A	Inco	None	5.72	0.01010	12
Filter J19D	Inco	None	5.72	0.00713	12

Table 17. PAH concentrations found on personal sampler filter and resin samples collected on board an A6L-714 Deutz diesel with no exhaust treatment device.

SAMPLE	PAH concentrations in ng/m3 of air sampled						
	FILTER & RESIN S16	FILTER D20	FILTER N22	FILTER D6	FILTER D13	FILTER D14	FILTER F28
PYRENE	4128.79	1971.96	4464.39	0.00	0.00	1692.38	1885.33
FLUORANTHENE	200.58	5.61	0.00	0.00	0.00	0.00	0.00
BENZO(a)ANTHRACENE	342.26	299.61	345.65	0.00	0.00	62.41	5.75
BENZO(e)PYRENE	1140.21	491.85	594.45	0.00	744.12	373.99	337.12
PERYLENE	15.83	1.45	3.86	0.00	2.05	0.81	1.57
3-METHYLCHOLANTHRENE	43.01	0.00	0.00	0.00	0.00	0.00	6.54
BENZO(k)FLUORANTHENE	0.00	0.00	0.00	467.76	0.00	0.00	6.81
BENZO(a)PYRENE	45.62	0.00	19.06	1085.33	3.04	2.11	6.43
BENZO(ghi)PERYLENE	183.86	0.00	0.00	4323.16	82.99	0.00	0.00
DIBENZO(def,mno)CHRYSENE	6.23	0.00	9.29	1.95	1.11	0.00	2.66
DIBENZO(a,h)ANTHRACENE	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NAPHTHO(1,2,3,4,def)CHRYSENE	417.87	0.00	0.00	42.13	14.56	172.99	0.00
BENZO(rst)PENTAPHENE	52.59	0.00	0.00	0.00	12.86	0.00	7.36
TOTAL PAHs	6576.87	2770.48	5436.71	5920.33	860.71	2304.69	2259.58
TOTAL PAHs-PYRENE	2448.08	798.52	972.32	5920.33	860.71	612.31	374.25
CARCINOGENS	1085.22	299.61	364.72	5450.63	113.44	237.51	26.09

Table 17(cont'd). PAH concentrations found on personal sampler filter and resin samples collected on board an A6L-714 Deutz diesel with no exhaust treatment device.

	PAH concentrations in ng/m3 of air sampled						
SAMPLE	RESIN D13,14	RESIN D15,16	RESIN D20	RESIN N22	RESIN D6	AVERAGE FILTER	AVERAGE RESIN
PYRENE	897.00	0.00	300.73	0.00	0.00	2020.41	239.55
FLUORANTHENE	9.46	0.00	0.00	0.00	0.00	29.46	1.89
BENZO(a)ANTHRACENE	62.81	0.00	36.97	35.86	0.00	150.81	27.13
BENZO(e)PYRENE	0.00	0.00	107.72	2070.65	0.00	525.96	435.67
PERYLENE	0.00	0.00	0.79	0.00	0.00	3.65	0.16
3-METHYLCHOLANTHRENE	0.00	0.00	0.00	0.00	0.00	7.08	0.00
BENZO(k)FLUORANTHENE	0.00	14.23	0.00	0.00	0.00	67.79	2.85
BENZO(a)PYRENE	0.00	0.00	0.00	0.00	0.00	165.94	0.00
BENZO(ghi)PERYLENE	0.00	0.00	0.00	0.00	0.00	655.72	0.00
DIBENZO(def,mno)CHRYSENE	0.00	0.00	0.00	0.00	0.00	3.03	0.00
DIBENZO(a,h)ANTHRACENE	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NAPHTHO(1,2,3,4,def)CHRYSENE	3.48	0.00	0.00	0.00	0.00	92.51	0.70
BENZO(rst)PENTAPHENE	0.00	0.00	0.00	0.00	0.00	10.40	0.00
TOTAL PAHs	972.75	14.23	446.20	2106.51	0.00	3732.77	707.94
TOTAL PAHs-PYRENE	75.75	14.23	145.47	2106.51	0.00	1712.36	468.39
CARCINOGENS	66.29	0.00	36.97	35.86	0.00	1082.46	27.82

samples collected on board the diesel are quite similar to those obtained with the Hi Vol samples collected at the sampling site, i.e., only the more volatile, lower molecular weight, PAHs seem to pass through the filter and collect on the XAD-2 resin. However, the reason for the similar distribution of PAHs in the two sampling systems may be fortuitous.[5]

The results in Table 18 give the PAH concentrations found with the personal sampler filter samples collected on board an A6L-714 Deutz diesel with 1) no exhaust treatment device, 2) with a fume diluter, 3) with a CTO, or 4) with a CTO and fume diluter in series. Table 19 gives the average PAH concentrations in the operator's breathing zone for the bare engine and each exhaust treatment system and Table 20 gives the ratio of the average PAH concentrations found with each exhaust treatment device and the bare engine. The results in Tables 19 and 20 show that the fume diluter is very effective in lowering the operator's exposure to the exhaust. In fact, adding the fume diluter to the bare engine reduces the operator's exposure to all of the PAHs. The exposure to the individual PAHs is reduced to between 4% and 73% of the bare engine values while the exposure to the Total PAHs is reduced by a factor of three, i.e., to 36% of the value found with the bare engine. The reduction in the Total-Pyrene and Total Carcinogens is even greater than for the Total PAHs. The Total-Pyrene and Total Carcinogens are reduced to 26% and 16%, respectively, of the bare engine values. Thus, the Total Carcinogens are reduced almost 6 times by the addition of the fume diluter.

The CTO-fume diluter combination, on the other hand, is not quite so effective. Although the operator's exposure to all of the PAHs is lower when the CTO-fume diluter combination is used, the Total PAHs in the operator's breathing zone are only reduced to 50% of those experienced with the bare engine. The CTO-fume diluter reduces the exposure to the Total-Pyrene and Total Carcinogens to 31% and 19%, respectively, of the bare engine values. It is surprising that the reduction in the PAH concentrations in the operator's breathing zone are smaller for the CTO-fume diluter combination than for the fume diluter alone.

The results found with the CTO alone indicate that the CTO only reduces the operator's exposure to PAHs slightly. In fact, three of the PAHs are

Table 18. PAH concentrations found from personal sampler filter samples collected on board an A6L-714 Deutz diesel fitted with a) no exhaust treatment device, b) a fume diluter, c) a CTO and d) a CTO and a fume diluter.

	PAH concentrations in mg/m3 of air sampled					
SAMPLE	BARE ENGINE 020	BARE ENGINE N22	BARE ENGINE D6	BARE ENGINE D13	BARE ENGINE D14	BARE ENGINE F28
PYRENE	1971.96	4464.39	0.00	0.00	1692.38	1885.33
FLUORANTHENE	5.61	0.00	0.00	0.00	0.00	0.00
BENZO(a)ANTHRACENE	299.61	345.65	0.00	0.00	62.41	5.75
BENZO(e)PYRENE	491.85	594.45	0.00	744.12	373.99	337.12
PERYLENE	1.45	3.86	0.00	2.05	0.81	1.57
3-METHYLCHOLANTHRENE	0.00	0.00	0.00	0.00	0.00	6.54
BENZO(k)FLUORANTHENE	0.00	0.00	467.76	0.00	0.00	6.81
BENZO(a)PYRENE	0.00	19.06	1085.33	3.04	2.11	6.43
BENZO(ghi)PERYLENE	0.00	0.00	4323.16	82.99	0.00	0.00
DIBENZO(def,mno)CHRYSENE	0.00	9.29	1.95	1.11	0.00	2.66
DIBENZO(a,h)ANTHRACENE	0.00	0.00	0.00	0.00	0.00	0.00
NAPHTHO(1,2,3,4,def)CHRYSENE	0.00	0.00	42.13	14.56	172.99	0.00
BENZO(rst)PENTAPHENE	0.00	0.00	0.00	12.86	0.00	7.36
TOTAL PAHs	2770.48	5436.71	5920.33	860.71	2304.69	2259.58
TOTAL PAHs-PYRENE	798.52	972.32	5920.33	860.71	612.31	374.25
CARCINOGENS	299.61	364.72	5450.63	113.44	237.51	26.09

Table 18. (cont'd) PAH concentrations found from personal sampler filter samples collected on board an A6L-714 Deutz diesel fitted with a) no exhaust treatment device, b) a fume diluter, c) a CTO and d) a CTO and a fume diluter.

	PAH concentrations in ng/m3 of air sampled					
SAMPLE	FUME DIL F1	FUME DIL F3	CTO D20	CTO D22	CTO & FD F10	CTO & FD F13
PYRENE	902.51	913.51	987.67	2852.82	2365.31	303.12
FLUORANTHENE	5.63	4.70	3.52	11.44	27.93	2.03
BENZO(a)ANTHRACENE	56.09	25.84	22.76	56.41	66.63	23.70
BENZO(e)PYRENE	368.27	176.18	838.05	472.02	500.01	93.18
PERYLENE	0.00	0.96	2.22	0.00	4.39	0.00
3-METHYLCHOLANTHRENE	0.00	7.31	0.00	0.00	0.00	0.00
BENZO(k)FLUORANTHENE	0.00	0.00	0.00	0.00	17.02	0.00
BENZO(a)PYRENE	0.00	54.88	0.00	4.66	24.91	0.00
BENZO(ghi)PERYLENE	15.52	39.94	0.00	71.71	125.34	21.77
DIBENZO(def,mno)CHRYSENE	0.00	1.32	0.00	0.00	3.74	0.00
DIBENZO(a,h)ANTHRACENE	0.00	0.00	0.00	0.00	0.00	0.00
NAPHTHO(1,2,3,4,def)CHRYSENE	85.16	50.05	201.09	67.63	42.81	75.21
BENZO(rst)PENTAPHENE	0.00	4.06	43.63	62.65	25.75	11.82
TOTAL PAHs	1433.17	1278.74	2098.95	3599.34	3203.84	530.83
TOTAL PAHs-PYRENE	530.67	365.24	1111.28	746.52	838.53	227.70
CARCINOGENS	156.76	182.08	267.49	263.06	285.43	132.49

Table 19. The average PAH concentrations found from personal sampler filter samples collected on board an A6L-714 Deutz diesel fitted with a) no exhaust treatment device, b) a fume diluter, c) a CTO and fume diluter and d) a CTO.

PAH concentration in ng/m3 of air sampled.

SAMPLE	AVERAGE BARE ENGINE	AVERAGE FUME DILUTER	AVERAGE CTO & FD	AVERAGE CTO
PYRENE	1669.01	908.01	1334.22	1920.25
FLUORANTHENE	0.93	5.17	14.98	7.48
BENZO(a)ANTHRACENE	118.90	40.96	45.16	39.59
BENZO(e)PYRENE	423.59	272.22	296.60	655.04
PERYLENE	1.62	0.48	2.19	1.11
3-METHYLCHOLANTHRENE	1.09	3.65	0.00	0.00
BENZO(k)FLUORANTHENE	79.09	0.00	8.51	0.00
BENZO(a)PYRENE	186.00	27.44	12.45	2.33
BENZO(ghi)PERYLENE	734.36	27.73	73.55	35.86
DIBENZO(def,ano)CHRYSENE	2.50	0.66	1.87	0.00
DIBENZO(a,h)ANTHRACENE	0.00	0.00	0.00	0.00
NAPHTHO(1,2,3,4,def)CHRYSENE	38.28	67.60	59.01	134.36
BENZO(rst)PENTAPHENE	3.37	2.03	18.78	53.14
TOTAL PAHs	3258.75	1355.96	1867.34	2849.15
TOTAL PAHs-PYRENE	1589.74	447.95	533.12	928.90
CARCINOGENS	1082.00	169.42	208.96	265.27

Table 20. A comparison of the average PAH concentrations found on personal sampler filter samples collected on board an A6L-714 Deutz diesel fitted with various exhaust treatment devices.

SAMPLE	F.D. Bare	CTO & FD Bare	CTO Bare
PYRENE	0.45	0.66	0.95
FLUORANTHENE	0.18	0.51	0.25
BENZO(a)ANTHRACENE	0.27	0.30	0.26
BENZO(e)PYRENE	0.52	0.56	1.25
PERYLENE	0.13	0.60	0.30
3-METHYLCHOLANTHRENE	0.52	0.00	0.00
BENZO(k)FLUORANTHENE	0.00	0.13	0.00
BENZO(a)PYRENE	0.17	0.08	0.01
BENZO(ghi)PERYLENE	0.04	0.11	0.05
DIBENZO(def,mno)CHRYSENE	0.22	0.62	0.00
DIBENZO(a,h)ANTHRACENE	-	-	-
NAPHTHO(1,2,3,4,def)CHRYSENE	0.73	0.64	1.45
BENZO(rst)PENTAPHENE	0.20	1.81	5.11
TOTAL PAHs	0.36	0.50	0.76
TOTAL PAHs-PYRENE	0.26	0.31	0.54
CARCINOGENS	0.16	0.19	0.25

present in higher concentration when the CTO is used and the CTO only reduces the exposure to the Total PAHs by 24% or to 76% of the values found with the bare engine (Table 20). Moreover, the CTO alone only reduces the Total-Pyrene and Total Carcinogens to 54% and 24% of the values found with the bare engine. Although the CTO reduces the PAHs on board the diesel, it is not nearly as effective as the fume diluter or the CTO-fume diluter options. In fact, the fume diluter appears to be the most effective device for reducing operator exposure. This might, in fact, have been predicted because the fume diluter directs or blows the exhaust away from the operator whereas the CTO only reduces the harmful components of the exhaust but does not change the emission pattern of the exhaust from the diesel. It is surprising that the CTO-fume diluter combination is not better than the fume diluter in reducing the PAH exposure of the operator. However, it is possible that this conclusion is the result of experimental error. Unfortunately, we were unable to analyze enough samples to make this comparison more certain.

The PAH concentrations found in the personal sampler filter samples collected on board a F8L-714 Deutz diesel operating in a production stope at Inco Metals Company Limited's Little Stobie mine, Tables 21 and 22, show the effect of the Corning Diesel Exhaust filter on the operator exposure. In fact, both the averages and the ratio of the PAHs found with the Corning filter and the bare engine, Table 22, show that the Corning filter, much like the CTO tested at Strathcona mine, does not reduce operator exposure to PAHs significantly. Although the exposure to only two of the PAHs is higher when the Corning filter is used, the Total PAHs with the Corning filter on the diesel are only reduced to 65% of the bare engine value, i.e., the Corning filter only reduces the operator's exposure by 35%. Moreover, the Total-Pyrene PAHs are only reduced by 3% and the Total Carcinogens by only 17% by the Corning filter. Thus, it appears that the Corning filter does not have a significant effect on the PAH levels near the scoop tram operator. Again, these conclusions are only based on a few analyses and we are not certain that the changes in operator exposure caused by the Corning filter will be born out by other testing. However, it appears that the Corning filter does not have a large effect on the PAH concentrations near the scoop tram operator.

Table 21. PAH concentrations found from personal sampler filter samples collected on board a F8L-714 Deutz diesel fitted with a) no exhaust treatment device and b) with a Corning filter.

	PAH concentrations in ng/m3 of air sampled.			
SAMPLE	BARE ENGINE J19A	BARE ENGINE J19D	CORNING J23	CORNING J25
PYRENE	2326.83	631.78	1371.73	275.35
FLUORANTHENE	0.00	28.03	8.41	9.92
BENZO(a)ANTHRACENE	69.36	18.02	42.15	62.80
BENZO(e)PYRENE	337.77	220.16	578.25	0.00
PERYLENE	1.55	0.00	1.18	0.00
3-METHYLCHOLANTHRENE	9.27	4.32	0.00	0.00
BENZO(k)FLUORANTHENE	0.00	0.00	4.75	0.00
BENZO(a)PYRENE	7.26	8.79	3.58	4.49
BENZO(ghi)PERYLENE	26.92	35.33	12.05	23.99
DIBENZO(def,mno)CHRYSENE	2.06	0.67	1.17	0.00
DIBENZO(a,h)ANTHRACENE	0.00	0.00	0.00	0.00
NAPHTHO(1,2,3,4,def)CHRYSENE	0.00	23.70	0.00	20.15
BENZO(rst)PENTAPHENE	0.00	4.35	0.00	4.15
TOTAL PAHs	2781.01	975.16	2023.28	400.86
TOTAL PAHs-PYRENE	454.19	343.38	651.54	125.51
CARCINOGENS	112.81	94.52	57.78	115.58

Table 22. A comparison of the average PAH concentrations found on personal sampler filter samples collected on board a F8L-714 Deutz diesel fitted a) with no exhaust treatment device and b) with a Corning diesel exhaust filter.

SAMPLE	PAH concentration in mg/m3 of air sampled		
	AVERAGE BARE ENGINE	AVERAGE CORNING	CORNING / BARE
PYRENE	1479.31	823.54	0.56
FLUORANTHENE	14.01	9.17	0.65
BENZO(a)ANTHRACENE	43.69	52.48	1.20
BENZO(e)PYRENE	278.96	289.13	1.04
PERYLENE	0.78	0.59	0.76
3-METHYLCHOLANTHRENE	6.79	0.00	0.00
BENZO(k)FLUORANTHENE	0.00	2.37	-
BENZO(a)PYRENE	8.03	4.03	0.50
BENZO(ghi)PERYLENE	31.13	18.02	0.58
DIBENZO(def,mno)CHRYSENE	1.36	0.58	0.43
DIBENZO(a,h)ANTHRACENE	0.00	0.00	-
NAPHTHO(1,2,3,4,def)CHRYSENE	11.85	10.08	0.85
BENZO(rst)PENTAPHENE	2.18	2.08	0.95
TOTAL PAHs	1878.09	1212.07	0.65
TOTAL PAHs-PYRENE	398.78	388.53	0.97
CARCINOGENS	103.66	86.68	0.84

AMES TESTS OF THE DIFFERENT EXHAUST TREATMENT SYSTEMS

HI VOL FILTER AND RESIN SAMPLES

At least two out of each set of eight Hi Vol filter samples collected downstream from a Deutz diesel, fitted with a particular exhaust treatment system, were analyzed with a multi-strain Ames bioassay. In addition, with one exception, at least one of the Hi Vol resin samples from each exhaust treatment system was analyzed with a single strain (TA98 without S-9) Ames bioassay. The data obtained in each Ames bioassay is presented in the appendix.

Ames Bioassays With TA98 Without Metabolic Activation

A summary of the results obtained in the Ames bioassays of the extracts from the Hi Vol filter and resin samples with tester strain TA98 without metabolic activation, i.e., minus S-9, are given in Tables 23 and 24, respectively. The data in Tables 23 and 24 demonstrate that almost all of the mutagenic activity (mutagenic compounds) are in the Hi Vol filter extracts rather than in the resin extracts. In fact, no mutagenic material was detected in the extracts from the Hi Vol resin samples collected downstream from the bare A6L-714 Deutz diesel used at Falconbridge, the A6L-714 engine fitted with the CTO, or the bare F8L-714 Deutz diesel used at Inco. Small amounts of mutagenic material were detected in the Hi Vol resin extracts when the Corning filter and the PTX catalytic converter were used on the F8L-714 Deutz diesel at Inco. However, even in these samples, the amount of mutagenic material in the resin extract was small, i.e., it was only equal to 22% and 34% of that in the corresponding Hi Vol filter extracts. In fact, on average, the revertants/m^3 calculated for the resin sample only equal 8% of the revertants/m^3 found with the filter sample. This result is similar to that found in the PAH analyses, i.e., most of the material of concern is collected on the Hi Vol filter rather than on the Hi Vol resin.

TABLE 23. The mutagenicity in revertants/m3 found using Salmonella tester strain TA98 without metabolic activation on the extracts of Hi Vol filters collected downstream from Deutz diesels fitted with different exhaust treatment devices.

Test Configuration	Sample Number	Soluble Organic Fraction (mg)	Volume (m3)	Specific Activity	Rev/m3	Ave. Rev/m3
Inco	J19A	310.9	262.6	0.15	175.5	167.1
Bare Engine	J19D	321.8	223.1	0.11	158.7	
Inco	J23	310.2	721.9	0.64	275.0	250.9
Corning Filter	J24,25	231.0	280.9	0.13	106.9	
	A6	670.8	221.6	0.013	39.4	
	M7	179.7	425.0	1.51	638.5	
	A25	284.3	217.8	0.26	339.4	
	J5	358.9	572.0	0.17	106.7	
Inco	J11	74.1	263.5	0.41	115.3	149.2
PTX Catalyst	J13	107.3	254.4	0.40	183.1	

TABLE 23 (cont'd). The mutagenicity in revertants/m3 found using Salmonella tester strain TA98 without metabolic activation on the extracts of Hi Vol filters collected downstream from Deutz diesels fitted with different exhaust treatment devices.

Test Configuration	Sample Number	Soluble Organic Fraction (mg)	Volume (m3)	Specific Activity	Rev/m3	Ave. Rev/m3
Falconbridge Bare Engine	D15	128.2	245.9	0.20	104.3	81.8
	D13	124.4	209.6	0.10	59.4	
Falconbridge CTO	D22	123.6	512.8	0.22	55.0	44.3
	D30	110.6	561.0	0.17	33.6	
Falconbridge Fume diluter	F1D	118.9	268.0	0.20	88.7	66.9
	F1R	110.1	517.3	0.13	45.1	
Falconbridge CTO and Fume Diluter	F8L	147.0	484.7	0.21	63.7	60.3
	F8R	140.4	493.5	0.20	56.9	

Table 24. The mutagenicity in revertants/m3 found using Salmonella tester strain TA98 without metabolic activation on the extracts from Hi Vol resins collected downstream from Deutz diesels fitted with different exhaust devices.

Test Configuration	Soluble Organic Fraction (mg)	Volume (m3)	Specific Activity for TA98 without S-9	Rev/m3	Average Rev/m3
Inco Bare Engine	3.29	8.3	-ve	-	-
Inco Corning Filter	2.56 5.43	18.6 9.95	0.3 0.13	41.3 70.9	56.1
Inco PTX Catalyst	3.74	13.3	0.18	50.5	50.5
Falconbridge Bare Engine	8.47	15.0	-ve	-	-
Falconbridge CTO	17.53	35.2	-ve	-	-

The results of the Ames bioassays using tester strain TA98 without S-9 on the Hi Vol filter extracts, Table 23, indicate that the CTO, the fume diluter, and the CTO-fume diluter combination all reduce the mutagenicity of the air at the sampling site slightly. In fact, the mutagenicity of the air at the sampling site is only reduced by 47%, 18%, and 26% by the CTO, the fume diluter, and the CTO-fume diluter combination, respectively. The largest reduction is with the CTO. Although the mutagenicity of the exhaust is reduced by the CTO, the CTO does not reduce the mutagens as much as the PAHs. The CTO removed approximately 75% of the PAHs in the exhaust whereas it only reduced the mutagenicity by 47%. It should also be remembered that the CTO used in these tests developed a high back pressure after only a few hours of use. Whether a CTO that did not develop this back pressure would cause the same reduction in mutagens and PAHs is not known.

One would not expect the fume diluter to reduce the mutagens at the sampling site significantly. Although the revertants/m^3 in the air at the sampling site are slightly (18%) smaller when the fume diluter is used, the difference is small and may not be real. In fact, the mutagenicities for the fume diluter and the bare engine overlap and one is forced to conclude that the mutagenicities for these two devices are not statistically different. Thus, the fume diluter has little or no effect on the mutagens in the air at the sampling site. This conclusion is supported by the PAH analyses of the fume diluter exhaust. The fume diluter did not affect the PAH concentrations at the sampling site significantly.

The CTO-fume diluter combination reduces the mutagenicity of the air at the sampling site by 26%. Since the fume diluter does not affect the mutagen concentrations significantly, the CTO must reduce the mutagenicity of the air at the sampling site. What is surprising however, is that the effect of the CTO-fume diluter combination appears to be smaller than the effect of the CTO alone, i.e., the fume diluter and CTO only reduce the revertants/m^3 of the mine air by 26% whereas the CTO reduced the revertants/m^3 at the sampling site by 47%. However, the mutagenicities of the two sets of samples are close and the difference between them is not statistically significant at a high confidence level.

In the experiments with the F8L-714 Deutz diesel, the PTX catalyst seems to decrease the mutagenicity of the mine air at the sampling site slightly, i.e., by 11%, whereas the mutagenicity of the air downstream from the diesel is 50% higher when the Corning filter is used. However, the revertants/m^3 for both the PTX catalyst and the Corning filter bracket the results for the bare engine and the effects suggested by the average mutagenicities may not be real. In fact, there is some reason to suspect that the results for the PTX and for the Corning filter are not correct. The results for the PTX catalyst experiments are suspect because they are opposite to those found in a previous study. Mogan and coworkers reported that the PTX catalyst increased the mutagenicity of the exhaust almost twelve times rather than decreased it by 11%.[12] The mutagenicities for the Corning filter are suspect because the extracts from the Corning filter Hi Vol filters contained oil and were at least three times larger than the extracts from the bare engine at Falconbridge and other Deutz diesels we have sampled in underground mines. It was suspected that the F8L-714 diesel used in this test had an oil leak and that some of this oil was collected on the Hi Vol filter. This oil was toxic to the Salmonella bacteria used in the Ames bioassays. This made the Ames bioassays difficult to interprete and the results less certain. In any case, the results suggest that neither the PTX catalyst nor the Corning filter decrease the mutagenicity of the air downstream from the diesel significantly.

Thus, the CTO causes the greatest reduction in the mutagenicity of the air downstream from the diesel. The PTX catalyst and the fume diluter, on the other hand, have little or no effect on the mutagenicity of the air at the sampling site and the Corning Diesel Exhaust filter increases the mutagenicity of the air. Although the Ames results for the Corning filter and the PTX catalyst may not be accurate, it is clear that none of the exhaust treatment systems reduce the mutagenicity of the air downstream from the diesel markedly. Only the CTO reduces the mutagenicity of the mine air by a statistically significant amount.

Multi-strain Ames Bioassays of Hi Vol Filters

The samples collected from the Hi Vol filters were also subjected to Ames bioassays with two other tester strains of Salmonella bacteria, TA98NR

and TA98/1,8DNP$_6$. Generally, the mutagenicities of the filter extracts, Table 25, were small with tester strain TA98NR and negative with TA98/1,8DNP$_6$. One third of all the samples tested had a negative respose to the TA98NR tester strain and at least one of the two samples analyzed for 1) the bare A6L-714 diesel, 2) the bare F8L-714 diesel, 3) the A6L-714 diesel fitted with a fume diluter, and 4) the A6L-714 diesel fitted with a CTO, were negative when analyzed with the TA98NR tester strain. On the other hand, both the filter extracts obtained from 1) the CTO-fume diluter combination, 2) the PTX catalyst, and 3) the Corning Diesel Exhaust filter gave a positive response to tester strain TA98NR. Even in these samples, however, the mutagenicity of the air at the sampling site was much lower with the TA98NR tester strain than with the TA98 tester strain. The average percentage of the (mutagenicity of the mine air with TA98NR/mutagenicity of the mine air with TA98) was 32% for the CTO-fume diluter combination, 48% with the PTX catalyst, and 55% with the Corning filter. If one considers all of the samples with a positive response to tester strain TA98NR, the average mutagenicity in revertants/m^3 with tester strain TA98NR was only 48% of the mutagenicity found with tester strain TA98. If all the samples are considered, the average mutagenicity of the mine air downstream from Deutz diesels found using tester strain TA98NR was only 31% of that found with tester strain TA98. Thus, all of the mutagenicities are significantly lower with the TA98NR strain. These results are in excellent agreement with the effects found by other workers. Several other groups have reported that the mutagenicity with tester strain TA98NR is approxiamtely 50% of that found using tester strain TA98 without metabolic activation.[12]

Only one sample showed any activity with tester strain TA98/1,8DNP$_6$. In the one sample that gave a positive response, the mutagenicity with TA98/1,8DNP$_6$ was only 6% of that found with tester strain TA98 and was only 10% of that found with tester strain TA98NR. Since the other thirteen extracts gave a negative response to tester strain TA98/1,8DNP$_6$, it is safe to conclude that none of the exhaust treatment devices used in this study display any mutagenic activity with the tester strain TA98/1,8DNP$_6$. This conclusion is also supported by the results found in other studies. Several workers have found little or no mutagenic activity when the TA98/1,8DNP$_6$ tester strain is used on diesel exhaust extracts from a variety of sources.[12]

Table 25. The mutagenicity in revertants/m3 of Hi Vol filter samples using Salmonella tester strains TA98 without metabolic activation, TA98NP and TA98/1,8DNP6.

Exhaust Treatment Device	Sample Number	TA98-S9 Specific Activity	TA98-S9 Mutagenicity	TA98NP Specific Activity	TA98NP Mutagenicity	TA/1,8DNP6 Specific Activity	TA/1,8DNP6 Mutagenicity
FALCONBRIDGE							
Bare Engine	D15	0.20	104.3	0.07	-ve	-ve	-ve
	D15	0.10	59.4	-ve	-ve	-ve	-ve
Fume Diluter	F10	0.20	88.7	0.10	14.4	-ve	-ve
	F1R	0.13	45.1	-ve	-ve	-ve	-ve
CTO	D22	0.23	53.0	-ve	-ve	-ve	-ve
	D30	0.17	33.5	-ve	-ve	-ve	-ve
CTO and Fume Diluter	F8L	0.21	63.7	0.09	27.3	-ve	-ve
	F8R	0.20	56.9	0.04	11.4	-ve	-ve

Table 25 (cont'd). The mutagenicity in revertants/m3 of Hi Vol filter samples using Salmonella tester strains TA98 without metabolic activation, TA98NP and TA98/1,8DNP6.

Exhaust Treatment Device	Sample Number	TA98-S9 Specific Activity	TA98-S9 Mutagenicity*	TA98NR Specific Activity	TA98NR Mutagenicity*	TA/1,8DNP6 Specific Activity	TA/1,8DNP6 Mutagenicity*
INCO							
Bare Engine	J19A	0.15	175.5	0.11	130.2	-ve	-ve
	J19D	0.11	158.7	-ve	-ve	-ve	-ve
PTX	J11	0.41	115.3	0.19	53.4	-ve	-ve
	J13	0.40	183.1	0.20	91.6	-ve	-ve
Corning	J23	0.64	275.0	0.41	176.2	0.04	17.2
	J24,25	0.13	106.9	0.06	49.3	-ve	-ve
	A5	0.013	39.4	NM	NM	NM	NM
	A5	-ve	-ve	NM	NM	NM	NM
	A25	0.26	339.4	NM	NM	NM	NM
	M7	1.51	638.5	NM	NM	NM	NM
	J5	0.17	106.7	NM	NM	NM	NM

NM - Not Measured

* The volumes of air sampled and the weight of the organic extract for each sample are given in Table 25b.

Table 25b. The volume of air sampled and the weight of the soluble organic extract from the Hi Vol filters used in the Ames tests quoted in Table 25.

Exhaust Treatment Device	Date Code	Volume in m^3	Extract Weight in mg.
FALCONBRIDGE			
Bare Engine	D15	245.9	128.2
	D13	209.6	124.4
Fume Diluter	F10	268.0	118.9
	F1A	317.3	110.1
CTO	D22	512.8	123.6
	D30	561.0	110.6
CTO and Fume Diluter	F8L	484.7	147.0
	F8R	493.5	140.4
INCO			
Bare Engine	J19A	262.6	310.9
	J19D	223.1	321.8
PTX	J11	263.5	74.1
	J13	234.4	107.3
Corning Filter	J23	721.9	310.2
	J24,25	280.9	231.0
	A5	221.6	670.8
	A25	217.8	284.3
	M7	425.0	179.7
	J5	571.8	358.9

The above results show that most of the mutagenicity found with tester strain TA98 was lost with tester strain TA98NR and virtually all of the mutagenicity was absent when the TA98/1,8DNP$_6$ tester strain of Salmonella bacteria was used. This indicates that the mutagenic material is mainly, if not completely, nitrated. The TA98NR tester strain does not react with most mononitrated PAHs so the lower activity with this tester strain indicates that a significant portion of the mutagenicity found with TA98 is due to mononitrated compounds.[13] TA98/1,8DNP$_6$, on the other hand, does not react with most dinitro PAHs, the super mutagens. Thus, the virtual absence of mutagenic activity with TA98/1,8DNP$_6$ indicates that most of the mutagenic activity is due to dinitro-PAHs.[13] Certainly virtually all of the mutagenicity is due to nitrated species, presumably mono- and dinitrated PAHs. These conclusions are consistent with those published by other workers.[12]

Finally, the PTX and the Corning Diesel Exhaust filter have a greater mutagenic response with the tester strains TA98NR and TA98/1,8DNP$_6$ than the other exhaust treatment systems, i.e., both the TA98NR samples were positive for these catalysts whereas either one or none of the samples from the other exhaust treatment devices were positive with TA98NR. The Corning filter was also slightly different from the rest in that it was the only one with a positive response to TA98/1,8DNP$_6$. This suggests that there is slightly less nitrated PAHs in the exhaust downstream from the diesel when these exhaust treatment devices are used. This might be expected for the Corning filter which is a non oxidizing type of filter and should not oxidize NO to NO_2, i.e., the NO_2 and/or the nitric acid formed from it, is undoubtedly the reagent that nitrates the PAHs. We are unable to explain why the exhaust from the oxidizing PTX catalyst appears to have less nitrated PAHs.

A PAH AND MUTAGEN HISTORY OF A CORNING DIESEL EXHAUST FILTER

The PAHs and mutagens were determined at various times throughout the lifetime of a pair of Corning Diesel Exhaust filters on a F8L-714 Deutz diesel. This work was undertaken to ensure that the Corning filter remained effective over its lifetime. The PAH concentrations and mutagenic response with Salmonella tester strains TA98 without S-9, TA98NR, and TA98/1,8DNP$_6$ are given in Table 26. An examination of the data in this table shows that

Table 26. PAH and Mutagenic History# of a Corning Diesel Exhaust Filter on a F8L-714 Deutz diesel.

Sample Number	Approx. Hours of use	Concentration in ng/m3			revertants/m3		
		Total PAHs	Total-pyrene	Total Carcinogens	TA98-S9	TA98NR	TA98/1,8DNP6
J23	0	NM	NM	NM	275	176	17.2
J24,25	10	65.2##	41.5	10.8	107	49.3	-ve
MR7	226	96.1	58.0	28.9	NM	NM	NM
AP5	355	NM	NM	NM	39.4	NM	NM
AP25	450	NM	NM	NM	339	NM	NM
M7	506	NM	NM	NM	638	NM	NM
J5	652	NM	NM	NM	107	NM	NM

The Corning filter was removed on August 8, 1984 when the back pressure exceeded 35 inches of water.

The pyrene concantration was low so the concentration of Total PAHs is low.

NM Not measured.

there is no trend in either the PAHs or the mutagens over the lifetime of the filter. Although the Total PAHs appear to be significantly different in the two samples, the Total PAHs for the first sample are too low because there was an error in determining the amount of pyrene. In fact, when the error in the pyrene analysis is considered, the Total PAHs for the two samples are fairly close. The Total-Pyrene and the Total Carcinogens for the two samples are also similar. This suggests that there is little difference in the PAHs on the two days they were measured even though the samples were taken over 200 hours apart.

The concentrations of mutagens found with tester strain TA98 minus S-9 vary widely over the lifetime of the filter, i.e., from a low of 39 to a high of 639 revertants/m^3 or by more than 16 times. However, there is no trend in the mutagenicity of the air at the sampling sites. For example, a mutagenicity of 107 revertants/m^3 was found near the beginning and the end of the filter's life, i.e., after 10 hours and 652 hours of operation. The results with tester strains TA98NR and TA98/1,8DNP$_6$ appear to be different on the two days they were measured. This difference may not be real, however, because all of the mutagenicities found after 10 hours of operation are approximately a third of the values found when the filter was new. Thus, the <u>relative</u> mutagenicities found with the TA98NR and TA98/1,8DNP$_6$ tester strains are the same within the experimental error of the method. Although we were unable to analyze samples with the TA98NR and TA98/1,8DNP$_6$ tester strains towards the end of the filter's lifetime, our best guess is that the filter does not change significantly with use.

SULFUR EMISSIONS

The effect of each exhaust treatment device on the sulfur emissions was determined by analyzing total particulate samples collected at the sampling site for sulfur dioxide, sulfate ion and sulfuric acid. The sampling rate of approximately 2 L/min was maintained by calibrated Bendix personal sampler pumps. The total particulate samples were collected on two different types of 37 mm filters. Some samples were collected on "Maskery" filters[14] which trapped the sulfate ion, sulfuric acid and the sulfur dioxide in the mine air. Other total particulate samples were collected on

37 mm pallflex or silver membrane filters. These filters collected only the sulfate ion and sulfuric acid portion of the sulfur emissions from the diesel.

Table 27 gives the concentrations of both sulfur dioxide and sulfate ion (sulfuric acid?) found downstream from Deutz diesels with the different exhaust treatment devices. Table 27 also gives the percent sulfur compounds that exist as sulfate ion at the sampling site. In addition, the percent sulfate ion present as sulfuric acid on the filter when the analysis was done and the amount of sulfuric acid in the mine air at the sampling site are presented in Table 27.

The two oxidizing catalysts, the CTO and the PTX, increase the amount of sulfate ion in the air at the sampling site significantly. The CTO increases the amount of sulfate ion by approximately 70% while the CTO-fume diluter combination increases the amount of sulfate ion by approximately 40%. The PTX catalyst, on the other hand, increases the sulfate ion by more than 100%, i.e., by 2.2 times. These higher sulfate ion levels are expected because the CTO and PTX catalysts contain platinum which catalyzes the oxidation of carbon monoxide to carbon dioxide, hydrocarbons to carbon dioxide and water, and sulfur dioxide to sulfur trioxide. The sulfur trioxide reacts with water in the hot exhaust to form sulfuric acid.

The fume diluter and the Corning filter, on the other hand, are not oxidizing types of exhaust treatment devices. Thus, they do not increase the amount of sulfate ion in the air at the sampling site. In fact, the amount of sulfate ion in the air at the sampling site is lower when the fume diluter and the Corning filter are used, i.e., the fume diluter reduces the amount of sulfate ion by 22% and the Corning filter reduces it by 31% from the bare engine values. While the decrease in the amount of sulfate with both these exhaust treatment devices may not be significant, it is clear that neither of these devices increase the amount of sulfate in the mine air downstream from Deutz diesels.

These results are supported by the percent sulfur emissions that are present as sulfate ion (sulfuric acid?). Most of the sulfur comounds collected in these samples are present as sulfate ion when the CTO and PTX catalysts are used, i.e., sulfate ion represents between 56% ands 76% (an

Table 27. The effect of various exhaust treatment systems on the sulfur emissions in the air downstream from A6L-714 and F8L-714 Deutz diesels.

Condition	SO2 (mg/m3)	SO4 (mg/m3)	%SO4 = SO4 / (SO2 + SO4)	% SO4 as H2SO4	H2SO4 (mg/m3)
A6L-714					
Bare Engine	0.338	0.171	34	14	0.024
CTO	0.228	0.295	56	2.5	0.007
Fume Diluter	0.476	0.133	22	4.0	0.005
CTO + Fume Diluter	0.164	0.242	60	3.7	0.009
F8L-714					
Bare Engine	0.183	0.160	47	6.4	0.010
Corning Filter	NA	0.111	--	8.6	0.010
PTX Catalyst	0.110	0.344	76	6.7	0.023

average of 64%) of the sulfur compounds when the CTO and PTX catalysts are on the diesel. The percent sulfur compounds present as sulfate ion are significantly lower for the nonoxidizing exhaust treatment systems. The percent sulfur compounds present as sulfate ion only range from 22% to 47% (average 34%) when the nonoxidizing fume diluter or Corning filter are used.

Although most workers have assumed that all of the sulfate ion is in the form of sulfuric acid, our results have consistently indicated that this is not the case.[14] In fact, very little of the sulfate ion is present as sulfuric acid when the analyses is done. For example, the amount of sulfate ion that is present as sulfuric acid is, at most, only 14%. On average, only 6.6% of the sulfate ion in the mine air is sulfuric acid. Even when the PTX catalyst increases the sulfuric acid concentration in the air at the sampling site by more than 100%, the sulfuric acid concentration is only 2.5% of the long term TLV for sulfuric acid. Since all the other exhaust treatment systems decrease the amount of sulfuric acid in the mine air, it appears that the sulfuric acid levels are far below those which would be of concern from a health point of view.

The very small amounts of sulfuric acid in the mine air suggest that the sulfuric acid formed in the oxidizing catalysts must be converted into a benign form (sulfate ion) in the exhaust system or in the mine air. A possible explanation for the low amounts of sulfuric acid in the mine air is that ammonia, which is present in fairly large concentratations in diesel exhaust and can also be released in the mine air from the blasting operations, reacts with the sulfuric acid in the exhaust forming a neutral salt, ammonium sulfate, which is not of concern from a health point of view. If the reaction between sulfuric acid and ammonia occurs quickly in the mine air as our results suggest, the sulfur emissions will only be of minor importance in choosing an exhaust treatment system for the diesels used in underground mines. Thus, although the Corning filter and the fume diluter appear to be more attractive from a sulfate ion (sulfuric acid?) point of view, the lower amounts of sulfate ion released from these exhaust treatment systems are not necessarily a real advantage.

RESPIRABLE COMBUSTIBLE DUST

Nylon cyclones fitted with 25 mm. silver membrane filters were used to collect RCD (respirable combustible dust) samples downstream from the diesel at the sampling site. The sampling rate of two L/min was maintained with Bendix personal sampler pumps. The RCDs for each exhaust treatment system are given in Table 28. An examination of the table shows that both the Johnson Matthey-Engine Control Systems (CTO) and the PTX catalysts reduce the RCD significantly. This result was expected because these platinum containing catalysts burn (oxidize) the hydrocarbons in the exhaust to carbon dioxide and water. The surprising result, however, was that the CTO-fume diluter combination did not reduce the RCD at the sampling site. In fact, it increased the RCD by 20%. This was surprising because both the CTO amd the fume diluter (vide infra) reduce the RCD significantly. We are unable to explain this result.

A second surprise was that the fume diluter reduced the RCD at the sampling site by 50%. In fact, the fume diluter caused the greatest reduction in the RCD. This was surprising because the fume diluter did not affect either the PAHs or the mutagens at the sampling site (vide supra). We are unable to provide a rationale for these results.

Finally, the Corning Diesel Exhaust filter was found to be very successful in reducing the RCD in the air at the sampling site. In fact, the Corning filter reduced the RCD by 47%. This presumably occurs because the unburned hydrocarbons which are reponsible for the RCD, are adsorbed on the diesel particulate that is captured (removed from the exhaust) by the Corning filter.

Thus, the fume diluter, the Corning filter, and the CTO all reduce the RCD at the sampling site significantly. The PTX has a samller, but still positive, effect on the RCD downstream from the diesel. Only the CTO-fume diluter combination does not decrease the RCD at the sampling site.

Table 28. The RCDs in mg/m3 found downstream from Deutz A6L-714 and F8L-714 diesels fitted with various exhaust treatment devices.

Diesel	Exhaust Treatment	Experimental Values *	Average
A6L-714 at 100 cfm/bhp	none	0.58, 0.78, 0.89, 0.70, 0.11**	0.74
	CTO	0.19, 0.16, 0.63, 0.68, 0.56	0.44
	CTO & FO	0.85, 0.92	0.89
	FO	0.48, 0.26, 0.57, 0.16	0.37
F8L-714 at 169 cfm/bhp	none	0.60, 0.11	0.36
	PTX	0.29, 0.91**, 0.20	0.25
	Corning	0.18, 0.0, 0.28, 0.29	0.19

* See reference 14.

** An outlier -- not included in the average.

C O N C L U S I O N

AN ASSESSMENT OF THE DIFFERENT EXHAUST TREATMENT SYSTEMS

The results found for the five different exhaust treatment systems are summarized below. A numerical comparison, Table 30, is also presented.

THE JOHNSON MATTHEY-ENGINE CONTROL SYSTEMS CTO

The examination of the Johnson Matthey-Engine Control Systems CTO indicated that this filter was successful in reducing the PAHs and the mutagens in the air downstream from the diesel. In fact, the PAHs were reduced to approximately 25% and the mutagens to approximately 50% of their bare engine values by the CTO. The one surprising observation was that the CTO had little effect on the PAH concentrations in the operator's breathing zone, i.e., the CTO only reduced the operator's exposure to the Total PAHs by 24%. However, the operator's exposure to the Total Carcinogens in the exhaust was reduced by 75%. The small decrease in the operator's exposure to the Total PAHs is interesting and should be investigated further to see if it is correct and/or if it can be increased by changing the geometry of exhaust treatment system. The CTO also reduced the RCD in the air downstream from the diesel by 40%. Although the CTO increased the amount of sulfate in the air at the sampling site by 70%, the amount of sulfuric acid in the air was, in fact, significantly (70%) lower when the CTO was used. Finally, the CTO appeared to reduce the amount of particulate in the mine air and removed almost all of the odour from the diesel exhaust. Thus, the overall effect of the CTO was quite positive. However, the CTO units used in this study developed a very high back pressure after they had been on the diesel for a few hours, Table 29. This problem alone makes the CTO impractical for a mining vehicle. However, if the back pressure problem could be solved without changing the effects on the diesel exhaust, the CTO would be a marked improvement over the current generation of exhaust

Table 29. Back pressure on the Johnson Matthey - Engine Control Systems CTO.

Operating Time (minutes)	Back Pressure (in inches of water)	
	Left CTO	Right CTO
0	15	18
142	25	23
309	27	22
469	31	34
610	25	26
759	29	26
885	37	29
950	35	25
1260	37	31
1368	33	27
1511	29	24
1657	31	26
1839	42	37
1965	39	33
2126	39	35

treatment devices.

THE FUME DILUTER

The fume diluter, as expected, did not affect the concentrations of the PAHs or the mutagens at the sampling site downstream from the diesel. Surprisingly, however, it did seem to reduce the amount of sulfate and the amount of sulfuric acid found at the sampling site, i.e., the amount of sulfate ion was reduced by 22% and the amount of sulfuric acid by 80%. The RCD was also reduced by 50% when the fume diluter was used. The important observation however, was the great reduction the fume diluter caused in the PAH concentrations in the breathing zone of the diesel operator. In fact, the fume diluter reduced the operator's exposure to the Total PAHs by 64% and the Total Carcinogens by 84%. Thus, the fume diluter is an attractive device for reducing worker exposure to the worrisome components in diesel exhaust. It is worth noting, however, that although the fume diluter reduces the exposure to most of the pollutants generated by the diesel, it does not reduce the odour or the amount of particulate downstream from the diesel significantly. The only effect is experienced by the operator.

THE CTO-FUME DILUTER COMBINATION

The CTO-fume diluter combination reduces the PAHs and the mutagens downstream from the diesel. The PAHs are 78% lower and the mutagens 26% lower when the CTO-fume diluter combination is on the diesel. The CTO-fume diluter combination leads to an increase of 41% in the amount of sulfate ion at the sampling site although the amount of sulfuric acid is 64% lower when the CTO and fume diluter are used. The RCD is also increased, i.e., it is 20% higher when this exhaust treatment system is used. The CTO-fume diluter does decrease the operator exposure to PAHs, however. The Total PAHs on board the diesel are 50% lower and the Total Carcinogens are 81% lower when the CTO-fume diluter combination is installed on the diesel. From the point of view of the operator, probably the most important consideration, the CTO-fume diluter combination appears attractive. It would be worth testing the operator's exposure to the mutagenic compounds

in the exhaust when this type of exhaust treatment system is used.

THE PTX CATALYTIC CONVERTER

The PTX catalyst used in these tests reduced the PAHs significantly, i.e., by approximately 60%, but had little or no effect on the mutagens downstream from the diesel. However, these results are opposite to those reported by Mogan et al.[12] These workers found that a PTX catalyst increased the Total PAHs by 33% and the mutagenicity of the exhaust by more than 11 times. The PTX also increased the amount of sulfate ion and sulfuric acid at the sampling site by 2.2 and 2.3 times, respectively. However, the sulfuric acid was still far below the TLV value in the mine air. One positive effect of the PTX catalyst was that it reduced the RCD by 30%. Unfortunately, we were unable to determine how the PTX catalyst affected the operator's exposure to PAHs. Overall, the PTX is the least attractive of all the devices tested in this study.

THE CORNING DIESEL EXHAUST FILTER

The Corning Diesel Exhaust filter is attractive for several reasons. It reduces the PAHs at the sampling site by approximately 80%. It also reduces the amount of sulfate ion and sulfuric acid slightly, i.e., by 31% and 5%, respectively. Moreover, it reduces the RCD by 47%. Unfortunately, our results suggest that the Corning filter increases the mutagenicity of the air at the sampling site by 50% and only reduces the operator's exposure to the Total PAHs by 35% and the Total Carcinogens by 16%. This is the smallest decrease in the on board PAHs found in this study. However, the ability to remove PAHs downstream from the diesel and also to a lesser extent at the operator, and it's abiltity to reduce the sulfur emissions and the RCD make this filter worthy of more study. It would be interesting to determine the effect of the Corning filter on the PAHs on board the diesel to see if our preliminary results are correct. It is also important to check the effect of the Corning filter on the mutagenicity of the exhaust, particularly on board the diesel, because there is some possibility that these results are not correct.

Overall, the CTO looks promising if the problems with the back pressure can be overcome without affecting the performance of the catalyst. The Corning filter is attractive because it reduces the PAHs at the sampling site significantly and might reduce the mutagens significantly as well. The fume diluter, although the least exotic of the exhaust treatment devices, is very attractive because it removes the pollutants from the scoop tram operator's environment, the person that has the highest exposure to the exhaust. An interesting combination for further study would be a combination of the Corning filter and the fume diluter.

Table 30. A comparison of the different exhaust treatment systems on Deutz diesels.

	measured downstream from the diesel at the sampling site					measured on board the diesel	
Exhaust Treatment System	Change in Total PAHs	Change in the Mutagenicity	Change in Sulfate Ion	Change in Sulfuric Acid	Change in PCO	Change in Total PAHs	Change in Total Carcinogens
CTO	-75%	-47%	+70%	-70%	-40%	-24%	-75%
Fume Diluter	-11%	-18%	-22%	-80%	-50%	-64%	-84%
CTO & FD	-78%	-26%	+41%	-64%	+20%	-50%	-81%
PTX	-58%	-11%	+115%	+130%	-30%	Not measured	Not measured
Corning	-80%	+50%	-31%	-5%	-47%	-35%	-16%

EXPERIMENTAL

SAMPLE COLLECTION

Ambient and underground air samples were collected using both personal samplers and Hi Vol samplers. Glass fiber filters and gas absorbents were used as the collection media.

SAMPLING LOCATIONS

The actual experiments, which involved collecting exhaust samples both in front of the operator and downstream from the diesel engine, were performed in two different mine locations. The first sampling site was in the E2-E4 stope on the 2250 foot level of Falconbridge Ltd's Strathcona mine. This study involved collecting exhaust samples on board and downstream from a 145 horsepower, A6L-714 Deutz diesel engine with and without fume diluters and Johnson Matthey catalytic trap oxidizers (CTO) in the exhaust system of the diesel. The level plan for the stope, the sampling site, and the path of the diesel are shown in Figure 1. The ventilation rate was an average of 16,840 ± 720 cfm (116 cfm/bhp) during the sampling. The sampling sites and the LHD duty cycle were identical for all the tests. The LHD cycle was 78 ± 36 seconds in length and consisted of loading muck at muck pile A and then transporting it to muck pile B where it was dumped. The cycle was completed by transporting a load of muck back to muck pile A. The two muck piles were located against the side wall of the stope for two reasons. First, this enabled the diesel to perform a true mucking operation with a lug down of approximately 16 seconds at each loading site. Secondly, the position of the

muck piles ensured that the exhaust ports of the diesel remained in the center of the drift throughout the LHD duty cycle. This ensured that all of the exhaust would be transported by the ventilation towards the sampling site resulting in a constant particulate concentration throughout the sampling period at the sampling site .

The second location for sampling was the 1400 foot level of Inco Ltd's Little Stobie mine. Here, exhaust samples were collected on board and downstream from a 195 horsepower, F8L 714 Deutz diesel engine operating with and without PTX catalysts and Corning Diesel Exhaust Filters in the exhaust train. This was an actual production mining site so the level plan was always changing. Consequently, there were several sampling sites and different LHD duty cycles. The location of the muck piles varied depending on which rock face in the stope was blasted. The mucking operation always involved a lugdown of approximately 30 seconds. The LHD cycles varied from day to day because the muck was hauled and dumped either on a pile approximately 40 meters from the train loading site (B) or on the train (C), Figure 2. Obviously, the time of each LHD duty cycle varied with the location of the muck piles and the dump site. However, at all of the sampling sites, the ventilation rate remained constant at approximately 33,000 cfm (169 cfm/bhp).

SAMPLING SYSTEMS

Two different types of samplers were used to collect the diesel exhaust: High Volume or Hi Vol samplers and personal samplers (PS). The Hi Vol samplers were placed at least half a meter off the mine floor to reduce the chance of mine dust being collected. In Falconbridge Ltd's Strathcona mine, the Hi Vol samplers were placed downstream of the diesel with the filters

perpendicular to the ventilation flow. At Inco Ltd's Little Stobie mine, the Hi Vol samplers had to be placed on the side of the stope, and thus the filters were parallel to the ventilation flow. Eight by ten inch Pallflex T60A20 teflon coated glass fiber filters were used to collect the diesel particulate (PAHs) in all of the sampling.

The flow rate was recorded at the beginning and the end of the sampling period. The Hi Vol samplers were allowed to run until the flow rate had decreased to approximately 80% of the original value. At this point they were stopped, and the filters were removed and folded so the particulate was on the inside. Then the filters were sealed in a sterile polyethylene bag and stored in the laboratory freezer until they could be analyzed.

In order to trap any PAHs that may have passed through the filter, a gas absorbent trap was placed in series with the Hi Vol sampler. This trap consisted of a stainless steel tube containing approximately 55 mL of clean Amberlite XAD-2 absorbent. A portion of the air that had passed through the filter was drawn through the trap by a calibrated pump at a flowrate of approximately 20 L/min . Since the Hi Vol's flowrate was considerably greater than that of the pump, not all the air was able to pass through the absorbent. Therefore, a spider, Figure 3, located in the intake port, was used to collect a representative air sample behind the filter.

The personal samplers, Figure 4, were located at both the sampling sites, in close proximity to the Hi Vol samplers, and on the diesel in front of the operator, i.e., close to the operator's breathing zone. In most of the tests, the personal sampler used to collect the diesel exhaust consisted of 37 mm cassette containing a preweighed, 37 mm Pallflex T60A20 teflon coated glass fiber filter, a 12 mm glass tube tapered at each end containing 8 mL of

freshly cleaned Amberlite XAD-2 resin on a glass wool bed, and a calibrated Bendix or Dupont pump working at a flow rate of approximately 2 L/min. The parts of the sampling train were connected in series with tygon tubing.

The filter cassettes and resin-containing tubes were held upright by the use of plastic disks on retort stands, Figure 5. Each disk on the retort stand was capable of holding up to seven personal samplers. For sampling on the diesel, the retort stands and the personal samplers were placed in a box which was strapped to the top of the diesel to avoid movement. As many as fourteen personal samplers were used to obtain a sample on the diesel.

The flow rates through the personal samplers were recorded at the beginning, the end, and several times during the sampling period so the total volume of air sampled could be determined. At the end of the sampling period, the pumps were removed and the filter cassettes and tubes were plugged at each end. Upon returning to the laboratory, the filters were weighed and placed in sterile polyethylene bags. The absorbent tubes were also placed in sterile polyethylene bags, and both the filters and absorbent tubes were stored in the freezer until they could be analyzed.

In addition to the Hi Vol and personal sampler samples, a time-weighted-average percent CO_2 was collected at the sampling site in order to calculate the dilution ratio of the exhaust.

PREPARATION OF CLEAN ABSORBENT

The grains of the Amberlite XAD-2 absorbent purchased from BDH chemicals, Toronto, Ontario, were sticky and could not be separated. As a result, the absorbent had to be purified before it could be used. The cleaning procedure involved washing the absorbent several times with distilled water to remove

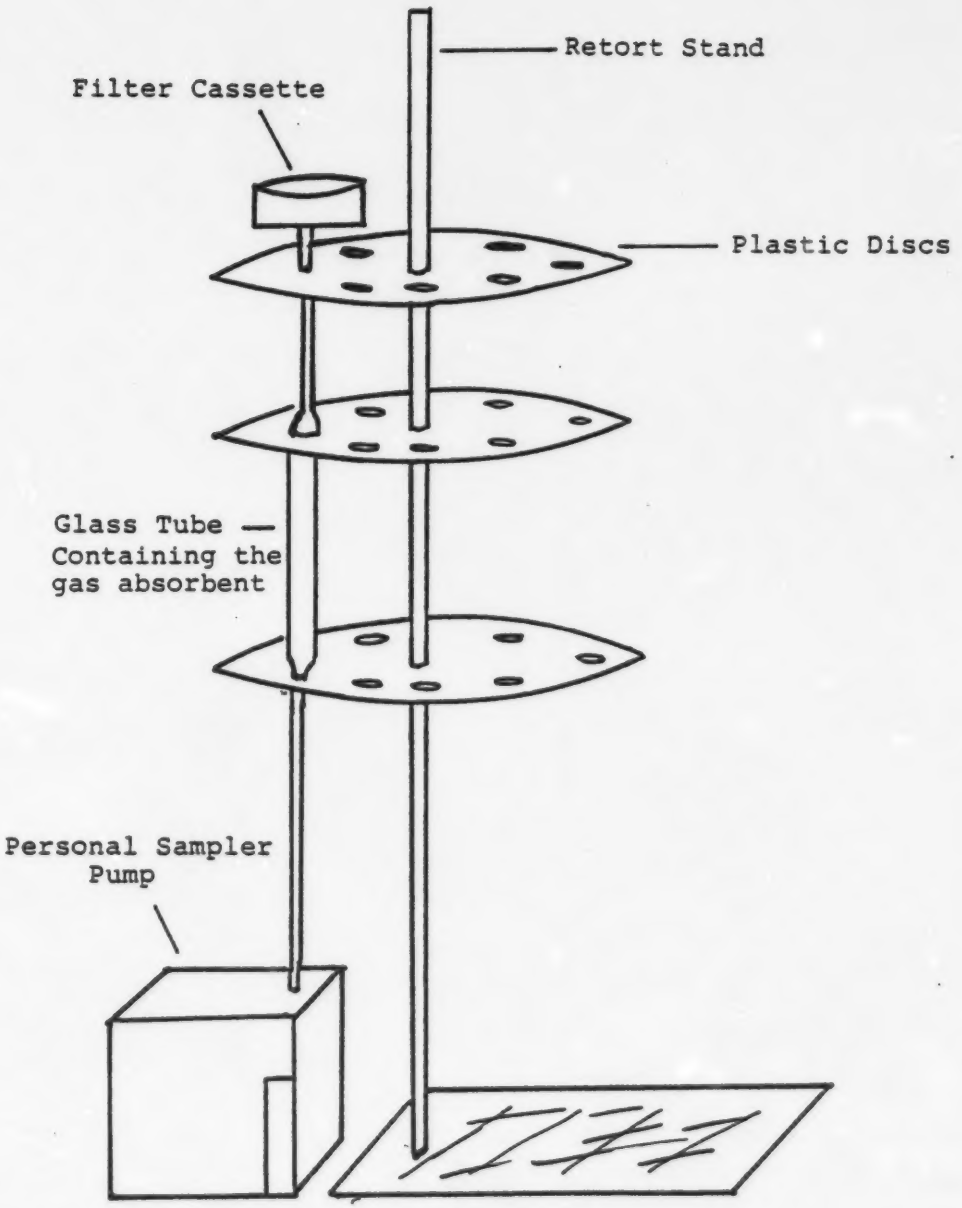

Figure 5 Apparatus used to hold the personal sampler system upright

any chloride ion that was present. Then the absorbent was placed in a soxhlet extractor and extracted for 24 hours each with distilled methanol and then with distilled in glass grade dichloromethane[1] in order to remove any hydrocarbons.

Finally, it was also necessary to clean the Amberlite XAD-2 absorbent before each sampling test since studies have shown it could be contaminated even if it has been exposed for a few days or kept tightly contained [4]. This cleaning involved placing 30 mL of XAD-2 absorbent in a 60 mL coarse sintered glass funnel and washing it with three, 30 mL aliquots of dichloromethane under a slight vacuum using a suction filtration technique. This procedure was repeated until a sufficient volume of absorbent for a day's sampling was obtained. The fairly dry absorbent was combined in a large crystallizing dish and most of the dichloromethane was removed by either shaking the dish or passing "extra dry" nitrogen over the resin. The resin was then poured through a powder funnel into a large specially made drying tube, Figure 6. The top of the drying tube was added and the apparatus was placed in a drying oven at 60 ^{o}C for eight hours with a slow stream of "extra dry" nitrogen passing through the tube. The stainless steel Hi Vol resin tubes were filled to either the 2" or 4" mark by pouring the resin directly from the drying apparatus. However, in order to fill the personal sampler tubes, the resin was transferred to crystallizing dish and drawn into the tubes by applying a slight vacuum to the end of the tubes.

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1. All distilled in glass grade solvents were purchased from Caledon Laboratories, Georgetown, Ontario.

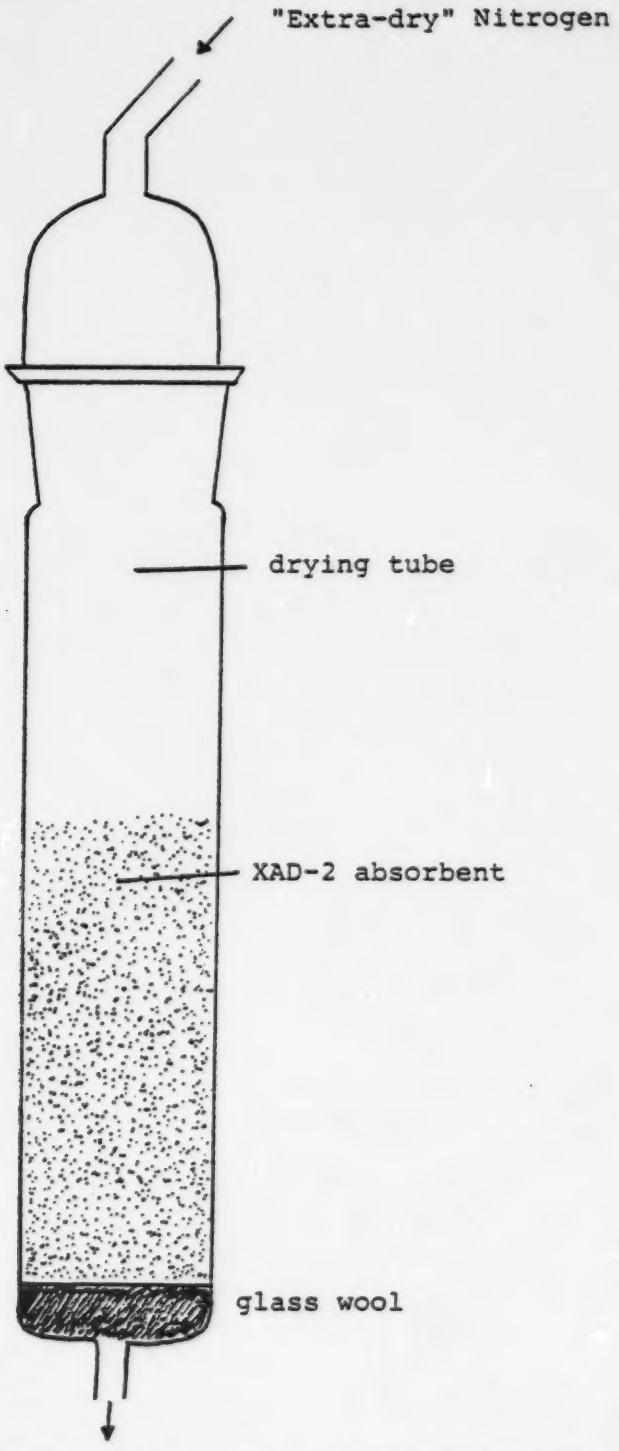

Figure 6 Apparatus used to dry the XAD-2 absorbent

ANALYSIS OF PAHs

SAMPLE EXTRACTION

Hi Vol Filters: The Hi Vol filter samples consisted of between 2 and 12 filters that were collected at a specific sampling site during either a single or double shift of diesel operation. Not more than one and a half of the Hi Vol filters from a sample were cut into one cm squares, placed in a tall form 400 mL beaker (Corning model 1040), and covered with 200 mL of distilled in glass grade benzene. The remaining filter(s) from the sample were placed in other beakers. All of the beakers were treated in a similar fashion. Each beaker was placed in an ice bath and covered with a clean piece of aluminum foil to prevent the loss of solvent through splashing or evaporation. The aluminum foil was punctured to allow the tip of 1.27 cm horn of a Heat System Inc., Model W-185F Sonicator to be placed 2 cm below the surface of the benzene-filter solution.

Then, the sample was sonicated for 10 minutes at maximum power (160-170 watts). The solvent was separated from the material in the beaker and collected in a 1000 mL round bottom flask using a suction filtration technique, Figure 7. The filter was returned to the tall 400 mL beaker, a second 150 mL portion of benzene was added, and the mixture was sonicated at 160-170 watts for another 10 minutes. The solvent was again removed by filtration through the sintered glass funnel. The filter was then sonicated with a third, 150 mL portion of benzene for 10 minutes at a power of 160-170 watts. The solvent was removed, and the filter was washed with five, 10 mL portions of benzene. Next, the filter was sonicated for 10 minutes at 160-170 watts with 200 mL of methanol. The methanol was removed by filtration through

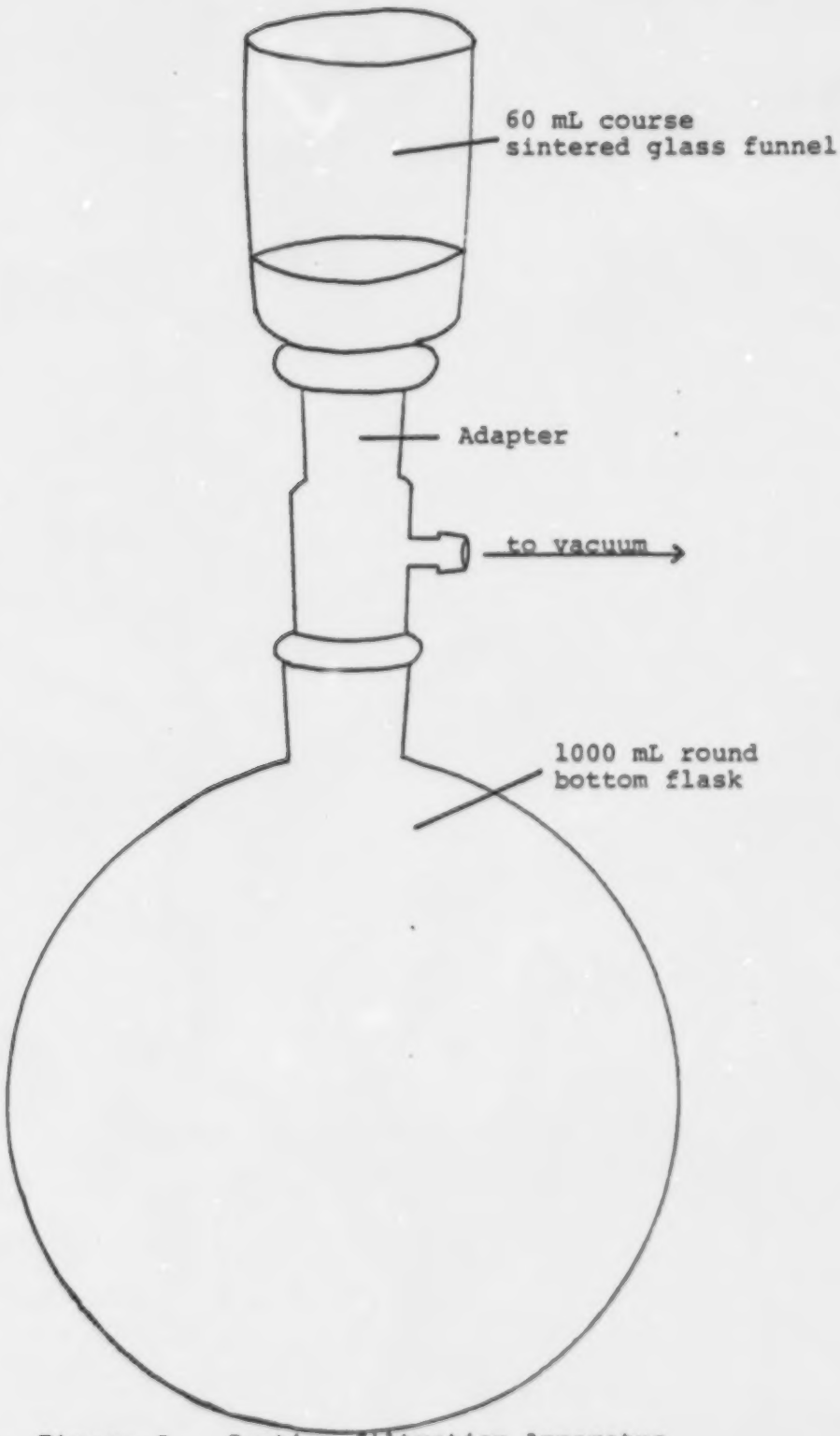

Figure 7 Suction filtration Apparatus

the same sintered glass funnel and discarded. Control tests have shown that the methanol does not remove any PAHs from the filter [15]. The filter was returned to the 400 mL beaker and sonicated two more times, for 10 minutes each, with 150 mL of benzene at 160-170 watts. After the final filtration, the filter was washed with five, 10 mL portions of benzene. After all the filters had been sonicated, they were combined and placed in two soxhlet extractors (without a thimble) and extracted with 250 mL of benzene overnight (12 to 18 hours). Each complete cycle in the soxhlet extractor required approximately 20 minutes.

The benzene from the soxhlet extractors was added to the benzene extracts in the round bottom 1000 mL flask, and the resulting mixture was reduced to dryness[1] on a rotary evaporator. The residue in the 1000 mL round bottom flask was then transferred into a 50 mL round bottom flask by washing the 1000 mL flask 3 times with approximately 10 mL of benzene. This 30 mL benzene solution was then evaporated to dryness on a rotary evaporator. This washing procedure with benzene was repeated. Then, the residue in the 50 mL round bottom flask was transferred with 6 or 7, 0.5 mL aliquots of dichlormethane to a weighed, one dram (3.7 mL) vial using a small glass funnel. This solution was evaporated to constant weight at room temperature using a slow stream of "extra dry" nitrogen. Near the end of this operation the walls of the vial were washed down with a small amount of dichloromethane. Finally, the vial was weighed and stored in the dark in the freezer

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1. The rotary evaporator was always operated at or below 40 ^{o}C to ensure that no PAHs evaporated.

until the next step of the analysis could be undertaken. This usually was only overnight because PAHs are less stable on the extract than they are on the diesel particulate [16].

Personal Sampler Filters: The procedure used in extracting the PAHs from personal sampler filters was identical to that used with Hi Vol filters except for two modifications. Since the combined personal sampler filters were considerably smaller than a Hi Vol filter, only 100 mL volumes of benzene and methanol were required for each sonication. Also because of the smaller amount of filter material, smaller soxhlet extractors containing approximately 40 mL of benzene, were used in the final extraction step.

Amberlite XAD-2 Absorbent: The absorbent from either the stainless steel tubes or the glass tubes that were used to trap the PAHs that had passed through the Hi Vol or the personal sampler filter, respectively, was dumped into a 1000 mL beaker. Each absorbent tube was then rinsed with a few milliliters of dichloromethane, and the washings were collected in the 1000 mL beaker. Then, approximately 200 mL of dichloromethane was added to the 1000 mL beaker, and the mixture was stirred for 10 minutes using a magnetic stirrer. The absorbent slurry was then vacuum filtered, and the solvent collected in a 1000 mL round bottom flask, Figure 7. The absorbent was returned to the 1000 mL beaker and extracted two more times. Then, the three dichloromethane extracts in the 1000 mL round bottom flask were reduced to dryness on a rotary evaporator. This extract was transferred to a weighed one dram (3.7 mL) vial and reduced to dryness by the same procedure that was used for the Hi Vol extract. The dried extract was stored in the dark in the freezer until the next step in the analysis could be completed.

QUANTITATIVE SEPARATION OF THE PAHs BY THIN-LAYER CHROMATOGRAPHY

Thin-layer chromatography (TLC) was used in two stages to separate the PAHs into pure compounds that could be analyzed. In the first TLC separation, the PAHs are separated from the other components in the extract and divided into four groups. The TLC plates used were 20 cm x 20 cm plates precoated with a 0.25 mm layer of aluminum oxide. They were purchased from Brinkman Instruments (Canada) Ltd., Rexdale, Ontario (catalogue number 66-14350-3). These plates were prepared for use by heating them at 110°C for 4 hours and then allowing them to equilibrate overnight in a room maintained at a humidity of 50 ± 5%. The plates were modified by drawing vertical lines through the aluminum oxide 6 mm from the side edges with a sharp pin. This improved the quantitative separations by reducing the edge effects.

The developing solvent was prepared by mixing 95 mL of distilled in glass grade pentane with 5 mL of redistilled, distilled in glass grade diethyl ether. This mixture was poured into a 21 cm x 21 cm x 8 cm five plate glass developing tank. Adding a 20 cm x 16 cm piece of Whatman No. 1 chromatography paper to the back of the chamber and allowing the tank to equilibrate for one half hour ensured uniformity of the solvent vapour in the tank.

A standard solution comprising approximately 200 ppm of pyrene, benzo(a)anthracene, perylene, benzo(ghi)perylene, and benzo(rst)pentaphene was prepared. Approximately 1 µL of this solution was spotted with a 2 µL capillary pipette, 1 cm in from each side line and 2.5 cm up from the bottom of the plate.

The vial containing the extract from the T60A20 Pallflex filters was mixed with 200 µL of toluene, and 100 µL of the resulting solution was spotted

using a 5 µL capillary pipette over a 12 cm range between the two standard spots. Each 5 µL pipette was discharged over a distance of 2 to 3 cm to keep the band as narrow as possible. The dilution factor, which represented the fraction of the extract that was used in the TLC analysis, was the ratio of the (total weight of the extract-toluene solution/the weight of the extract of the extract-toluene solution spotted).

The TLC plate was placed in the tank and allowed to develop until the pyrene band had travelled 15 cm. This normally took approximately 45 minutes. The progress of the pyrene band could be checked by shining a hand held UV lamp onto the plate in the developing tank. After the plate was removed and allowed to dry, the plate was placed in a light box fitted with a long wave UV lamp. The 4 bands containing the PAHs, i.e., those directly across from their respective standard spots on the developed TLC plate, were easily visible because of their fluorescence. Lines were drawn around each of the 4 groups of PAHs with a sharp pin. The heights of each band in a typical developed aluminum oxide TLC plate are given in Table 31.

The aluminum oxide in the area of the plate containing a single group of PAHs was loosened from the glass TLC backing plate. A pasteur pipette blocked with a small amount of glass wool in the sharp end, was inserted into a rubber stopper that was inserted into a vacuum adapter and a 50 mL round bottom flask, Figure 8. A vacuum was applied and 1 cm of aluminum oxide powder was drawn into the pasteur pipette. Typically 3 or 4 pasteur pipettes were required to collect all the aluminum oxide powder in each band. The pipettes were stacked one above the other in the above apparatus, and 30 mL of dichloromethane was allowed to percolate (no vacuum used) through the aluminum oxide powder in the pasteur pipettes and collect in the 50 mL round

Table 31. A typical development of the aluminum oxide TLC plates

Average distance travelled in mm (*,**)	Appearance under longwave UV light	Compounds
138	violet fluorescence	Probably aliphatic hydrocarbons and low molecular weight aromatic hydrocarbons
118	green fluorescence	Group A PAHs
98	blue fluorescence	Group B PAHs
84	yellow-green fluorescence	Group C PAHs
66	light green fluorescence	Group E PAHs
50-25	green fluorescence	below Group E probably heterocyclic aromatic compounds or nitrated aromatics

* The single numbers in this column refer to the center of the band. Most bands were ten to fifteen mm wide.

** The average distances varied by as much as ± 20 mm on different TLC plates. This did not pose any problem because known standards were run on each TLC plate.

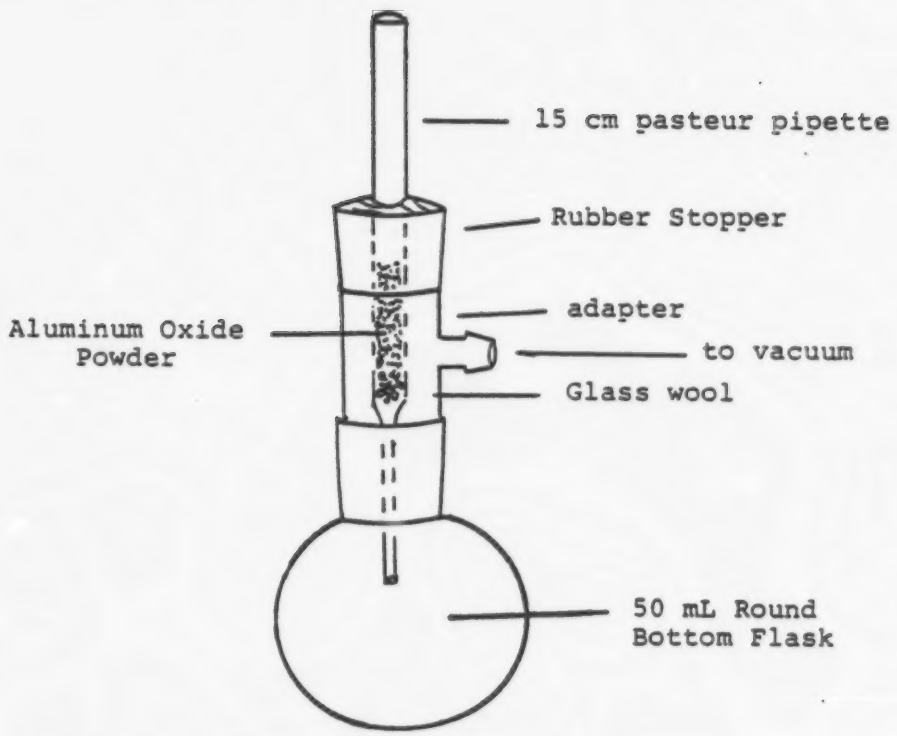

Figure 8 The apparatus used to extract the PAHs from the aluminum oxide powder

bottom flask. Then, the adapter was washed with 5 mL of dichloromethane, the round bottom flask was removed, and the dichloromethane was evaporated to dryness on a rotary evaporator. The PAH extract was then transferred via a small glass funnel to a one dram (3.7 mL) vial by rinsing the round bottom flask 6 or 7 times with 0.5 mL aliquots of dichloromethane. The solvent was then evaporated using a slow stream of "extra dry" nitrogen. Near the end of this operation the walls of the vial were washed down with a small amount of dichloromethane. This entire procedure was repeated for the 3 other bands of PAHs.

The second TLC separation, in which each group of PAHs was separated into pure compounds, was accomplished using 20 cm x 20 cm plastic-backed TLC plates precoated with 30% acetylated cellulose to a thickness of 0.1 mm. These plates were purchased from Brinkmann Instruments (Canada) Ltd., Rexdale, Ontario (catalogue no. 66-10201-6). Before using the TLC plates, they were fastened using paper clips to glass plates for added rigidity, and vertical lines were drawn through the adsorbent 6 mm from the side edges with a sharp pin to reduce edge effects. Finally, each plate was equilibrated for at least 24 hours at a relative humidity of 50 ± 5%.

The solvent used in the developing tank consisted of 50 mL of distilled 1-propanol and 25 mL each of distilled acetone and distilled H_2O. The tank was allowed to equilibrate for at least 30 minutes and a 20 cm x 16 cm piece of Whatman No. 1 chromatography paper was used to ensure uniformity of the solvent vapour.

The separation of each PAH group involved spotting the dried extract of each group along with standard solutions containing approximately 200 ppm of all of the PAHs in that group, on a single TLC plate. The group A standard

solution contained pyrene and benzo(a)anthracene; the group B standard solution contained benzo(e)pyrene, perylene, benzo(k)fluoranthene, and benzo(a)pyrene; the group C standard solution contained benzo(ghi)perylene and dibenzo(def,mno)chrysene; and the group E standard solution contained naphtho(1,2,3,4,def)chrysene and benzo(rst)pentaphene.

For each plate (PAH group) approximately 1 µL of the respective standard solution was spotted with a two µL capillary pipette, approximately 1 cm in from each edge line and 2.5 cm up from the bottom of the plate. Then the appropriate dried PAH extract was dissolved in 100 µL of cold toluene, and a known amount of this solution (approximately 80 µL) was spotted over the center 12 cm of the 30% acetylated cellulose TLC plate with a 2 µL capillary pipette. This spotting was done by discharging the pipette over 2 or 3 cm in order to keep the band as narrow as possible. The dilution factor for this group of PAHs was determined by dividing the weight of the total extract-toluene by the weight of the extract-toluene solution spotted.

The four acetylated cellulose plates were placed in the developing tank with the group B plate at the front. The chromatograms were developed for approximately 16 hours, i.e., until the perylene standard at the edges of the TLC plate (this could be seen by shining the hand-held UV lamp against the tank) had travelled 10 cm up the plate. After the TLC plates had been removed from the glass plates, they were allowed to air dry. The plates were examined in a light box containing a longwave UV lamp and the areas occupied by the individual PAHs were marked by drawing a line around the fluorescent bands with a sharp pin. Typical separations for each developed plate are given in Table 32.

Table 32. Typical separations on the 30% acetylated cellulose TLC plates

PAH Group	Distance* travelled in mm	Fluorescence under long wave UV light	Compound
A	122	blue	Unknown A1
	86	blue-green	Pyrene and fluoranthene**
	55	blue green	Benzo (a) anthracene
	17	blue green	Unknown A2
B	115	violet	Benzo (e) pyrene
	80	blue	Perylene and 3-methyl-cholanthrene[b]
	63	violet	Benzo (k) fluoranthene
	45	brown	Unknown B2 possibly benzo (j) fluoranthene or benzo (ghi) fluoranthene**
	35	green	Benzo (b) fluoranthene
	26	violet	Benzo (a) pyrene
C	93	voilet	Benzo (ghi) perylene
	64	brown	Dibenzo (a,h) anthracene
	42	yellow	Dibenzo (def,mno) chrysene
E	91	blue violet	Naphtho (1,2,3,4,def) chrysene
	37	blue	Benzo (rst) pentaphene

*. The distance travelled refers to the center of the band. Most bands are approximately twelve mm wide

**. These bands are not pure compounds and contain other compounds not listed in the table.

Each band was cut using a pair of scissors into approximately 0.5 cm x 0.5 cm pieces. These pieces of the TLC plate were then placed in a 50 mL erlenmeyer flask fitted with a ground glass stopper. Twenty mL of deoxygenated[1] diethyl ether was added to each erlenmeyer flask, and the solution was left for at least one hour. Then, the ether was recovered by vacuum filtering the mixture in the erlenmeyer flask using the apparatus shown in Figure 10 except that the 1000 mL round bottom flask was replaced by a 50 mL round bottom flask. Next, the erlenmeyer flask as well as the funnel and adapter were washed twice with 5 mL of diethyl ether. Finally, the round bottom flask containing all of the ether was removed and the ether was evaporated to dryness using a rotory evaporator.

Each PAH (in the round bottom flask) was transferred via a small glass funnel into a calibrated 3 mL vial by rinsing the round bottom flask with 6 or 7, 0.5 mL aliquots of deoxygenated[1] pentane. The volume in the vial was reduced to 3 mL by evaporating the excess solvent with a slow stream of "extra dry" nitrogen. The resulting solutions of these individual PAHs were then analyzed by spectrofluorometry.

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1. Any oxygen was removed by bubbling "extra dry" nitrogen through the solvent for 15 minutes.

QUANTITATIVE ANALYSIS OF THE PAHs

A G. K. Turner model 430-025 spectrofluorometer with a xenon source and a 15 mm slit width was used for all the analyses. The calibration curves for all 13 PAHs that we were able to analyze quantitatively, were obtained by recording the emission and excitation spectra of standard solutions containing between 0.05 and 0.5 ppm of a PAH in deoxygenated pentane at a sensitivity setting that did not allow the most concentrated solutions to exceed the scale of the recorder. The actual calibration curve was obtained by plotting the height of the most intense peak in the excitation or emission spectra in mm against the concentration of the PAH in ppm, Figure 9.

All the spectrofluorometric analyses of the PAHs isolated from the ambient air and exhaust samples collected in dieselized underground mines were measured in deoxygenated pentane. The positions of all of the peaks in the emission and excitation spectra for each PAH are given in Table 32. The emission spectrum was recorded from a wavelength 30 nm higher than the wavelength of the smallest peak to the excitation wavelength. The excitation wavelength was set at the most intense peak in the excitation spectrum. The excitation spectra were recorded from a wavelength 10 nm lower than the emission wavelength to 200 nm. For these spectra the emission wavelength was set at the wavelength of the most intense peak in the emission spectrum.

Before each set of analyses, the intensity of the xenon lamp was standardized by measuring the height found for the 513 nm peak of the emission spectrum when a standard 0.12 ppm disodium fluorescein solution in 0.05 disodium hydrogen phosphate was analyzed at a sensitivity of 3 with an excitation wavelength of 491 nm. The height of the 513 nm emission peak for the standard disodium fluorescein solution was 103 mm when the calibration

Table 32. The sensitivity, the slope of the calibration curve, the wavelengths of the peaks in the emission and excitation fluorescence spectra and the wavelengths of the peaks used in quantitative analysis

PAH	SENSITIVITY	SLOPE OF CALIBRATION CURVE IN mm/ppm	PEAKS IN nm IN THE* EMISSION SPECTRUM	PEAKS IN nm IN THE* EXCITATION SPECTRUM
PYRENE	X100	432	386	243, 271, 333
FLUORANTHENE	X100	587	437, 459	240, 286, 350
BENZO(a)ANTHRACENE	X100	781	388, 406, 430, 460	287, 346
BENZO(e)PYRENE	X300	941	390	288, 330
PERYLENE	X3	614	439, 465, 493	254, 408
3-METHYLCHOLANTHRENE	X30	763	395, 416, 438	295, 360
BENZO(k)FLUORANTHENE	X30	1219	404, 428, 452	241, 305, 382
BENZO(a)PYRENE	X10	415	405, 427, 450	294, 366, 381
BENZO(ghi)PERYLENE	X100	760	420	296, 364, 382
DIBENZO(def,mno)CHRYSENE	X3	301	431, 456, 485	235, 306, 404
DIBENZO(a,h)ANTHRACENE	X100	1170	395, 415, 440	296, 335
NAPHTHO(1,2,3,4,def)CHRYSENE	X100	647	400, 415	301, 372
BENZO(rst)PENTAPHENE	X30	471	434, 459, 485	293, 371, 392

* The peak used in the quantitative analysis is underlined.

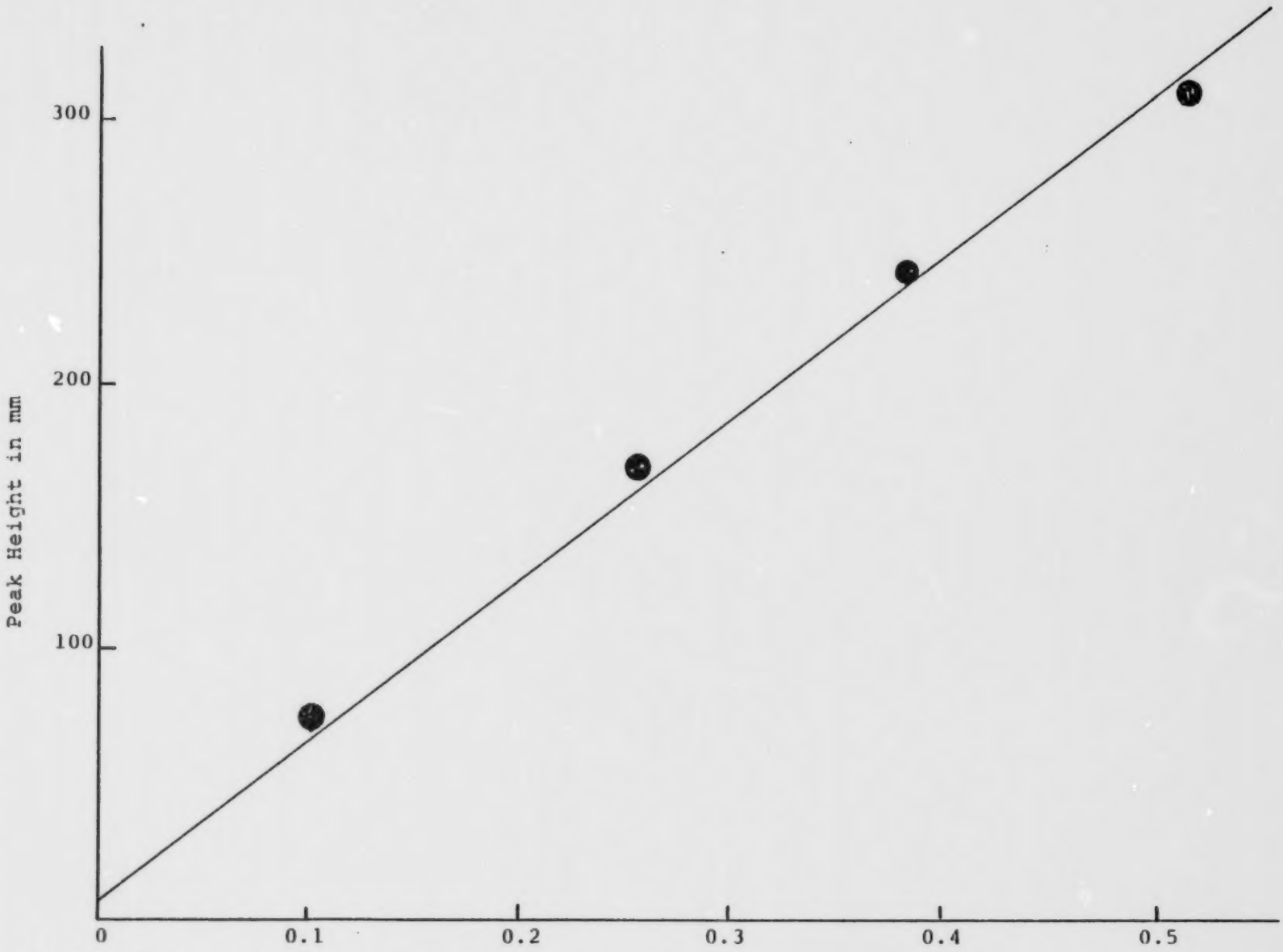

Figure 9 Typical calibration curve of peak height of the largest peak versus concentration of a PAH

curves were prepared. A sensitivity correction factor, S = (103 mm/ height in mm of the 513 nm peak), was determined for each set of analyses in order to adjust for any variations that occurred in the xenon source.

The emission spectrum was used to analyze all of the PAHs except pyrene, fluoranthene, B(e)P, B(rst)P, and N(1,2,3,4,def)C. In recording the spectra, the sensitivity was adjusted so that the height of the highest peak was neither off scale or too small to measure. The concentration of the PAHs were calculated using the following equation.

$$C = \frac{H \times DF_1 \times DF_2 \times V \times S \times 10^6}{M \times VA}$$

The variables are described as follows:

C is the concentration of the PAH in ng/m^3.

H is the corrected height (height x sensitivity) of the peak in mm.

DF_1 is the dilution factor in spotting the aluminum oxide TLC plate.

DF_2 is the dilution factor in spotting the 30% acetylated cellulose TLC plate.

V is the volume of the deoxygenated pentane solution used in the analysis. This was 3.0 mL in all the samples used in this study.

S is the sensitivity correction factor which adjusts for any differences between the intensity of the xenon lamp used in making the calibration curves and in the analysis.

M is the slope of the calibration curve (see Figure 9) and VA is the volume of mine air sampled in cubic meters.

QUANTITATIVE SEPARATION BY TLC OF PERSONAL SAMPLER FILTER AND ABSORBENT EXTRACTS AND HI VOL ABSORBENT EXTRACTS

The procedure that was used for the quantitative separation of the Hi Vol filters was used on the extracts from the personal sampler filters and the absorbent samples with the following modifications. On both the aluminum oxide and acetylated cellulose plates, the entire toluene-extract solution was spotted over an 8 cm rather than a 12 cm band range. This was to improve the intensity of the fluorescent bands which were obtained from the extracts. This was necessary because much smaller amounts of PAHs were collected with these sampling devices. When the aluminum oxide TLC plate of the personal sampler filter extract was developed and examined under UV light in the usual manner, there was generally only fluorescence found for groups A, B, and C, and no fluorescence was observed for group E PAHs. An examination of the aluminum oxide plate for the personal sampler absorbent and Hi Vol absorbent generally only showed fluorescence for the group A PAHs and no fluorescence was observed for the group B, C, and E PAHs. The four PAH bands were scraped from the aluminum oxide TLC plate in the usual manner even if no fluorescence was observed in the region of the TLC plate where a group of PAHs was expected.

Each group of PAHs was separated into individual PAHs on a 30% acetylated cellulose TLC plate in the usual manner. As with the aluminum oxide TLC plate, both the fluorescent and non-fluorescent regions of the acetylated cellulose TLC plates where the individual PAHs should have been found, were cut out, extracted, and analyzed using the procedure described earlier.

SULFUR DIOXIDE, SULFATE ION, AND SULFURIC ACID ANALYSES

The procedures used to collect and analyze these samples are described elsewhere[14].

RCD ANALYSES

The detailed sampling and analytical procedures used for these samples is described in reference 14.

AMES BIOASSAYS

Ames bioassays in this study were done by Mr. A. Horton of the Ontario Research Foundation in Mississauga, Ontario.

A C K N O W L E D G E M E N T S

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APPENDIX

TABLE 1: Ames Salmonella Mutagenicity Test Results for Inco bare engine:

Tester strain TA98 without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS					MEAN	STD. +/-	NET REV.
3000	-	400	318	328			349	45	327
1800	-	243	240	230			238	7	216
1500	-	213	209	178			200	19	178
1200	-	309	189	170			223	75	201
900	-	232	197	188			206	23	184
600	-	169	161	163			164	4	142
300	-	90	90	114			98	14	76
150	-	59	73	69			67	7	45
NEGATIVE CONTROL	-	28	30	20	15	17	22	6	
HISTORICAL CONTROL	-						26		
POSITIVE CONTROL	-	565		578		537	560	23	
HISTORICAL CONTROL	-						684		
2NF 2µg SPECIFIC ACTIVITY							0.15		

Tester strain TA98NR without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS					MEAN	STD. +/-	NET REV.
3000	-	163	148	144			152	10	132
1800	-	142	149	204			165	34	146
1500	-	155	149	173			159	12	140
1200	-	126	156	158			147	18	127
900	-	133	136	122			130	7	111
600	-	81	87	96			88	8	69
300	-	42	47	58			49	8	30
150	-	34	30	44			36	7	17
NEGATIVE CONTROL	-	21	24	17	17	18	19	3	
HISTORICAL CONTROL	-						17		
POSITIVE CONTROL	-	79		95		84	86	8	
HISTORICAL CONTROL	-						76		
2NF 2µg SPECIFIC ACTIVITY							0.11		

TABLE 1 (Con't):

Tester strain TA98/1,8DNP$_6$ without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS					MEAN	STD. +/-	NET REV.
3000	-	36	43	35			38	4	17
1800	-	35	31	40			35	5	14
1500	-	34	32	41			36	5	15
1200	-	43	37	29			36	7	15
900	-	34	47	54			45	10	24
600	-	39	33	48			40	8	19
300	-	43	33	38			38	5	17
150	-	29	31	24			28	4	7
NEGATIVE CONTROL	-	26	17	20	22	20	21	3	
HISTORICAL CONTROL	-						15		
POSITIVE CONTROL	-	71		81		76	76	5	
HISTORICAL CONTROL	-						81		
2NF 2µg SPECIFIC ACTIVITY							Negative		

TABLE 1A: Ames Salmonella Mutagenicity Test Results for Inco bare engine:

Tester strain TA98 without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS					MEAN	STD. +/-	NET REV.
2000	-	178	195	239			204	31	168
1400	-	190	197	172			186	13	150
1000	-	120	100	118			113	11	76
600	-	97	96	110			101	8	65
500	-	75	99	81			85	12	49
400	-	92	98	87			92	6	56
300	-	81	78	84			81	3	45
200	-	79	84	66			76	9	40
100	-	51	51	68			57	10	20
50	-	49	55	59			54	5	18
NEGATIVE CONTROL	-	29	30	49	41	32	36	8	
HISTORICAL CONTROL	-						31		
POSITIVE CONTROL	-	460		483		487	477	15	
HISTORICAL CONTROL	-						580		
2NF 2µg									
SPECIFIC ACTIVITY							0.11		

Tester strain TA98NR without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS					MEAN	STD. +/-	NET REV.
2000	-	83	89	66			79	12	64
1400	-	64	66	75			68	6	53
1000	-	54	66	42			54	12	39
600	-	38	41	56			45	10	30
500	-	39	43	43			42	2	26
400	-	35	41	47			41	6	26
300	-	53	44	63			53	10	38
200	-	35	46	31			37	8	22
100	-	46	24	39			36	11	21
50	-	55	31	23			36	17	21
NEGATIVE CONTROL	-	14	23	17	15	7	15	5	
HISTORICAL CONTROL	-						16		
POSITIVE CONTROL	-	83		68		64	72	10	
HISTORICAL CONTROL	-						74		
2NF 2µg									
SPECIFIC ACTIVITY							Negative		

TABLE 1A (Con't):

Tester strain TA98/1,8DNP$_6$ without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS			MEAN	STD. +/-	NET REV.
2000	-	21 Tox	17 Tox	Tox	Tox		
1400	-		Toxicity		Tox		
1000	-		Toxicity		Tox		
600	-	1	2	2	2	1	-12
500	-	3	3	2	3	1	-11
400	-	6	0	6	4	3	-10
300	-	1	0	2	1	1	-13
200	-	7	0	2	3	4	-11
100	-	0	4	1	2	2	-12
50	-	1	4	3	3	2	-11
NEGATIVE CONTROL	-	10	9 15	16 18	14	3	
HISTORICAL CONTROL	-				15		
POSITIVE CONTROL	-	38	56	47	47	9	
HISTORICAL CONTROL	-				64		
2NF 2µg SPECIFIC ACTIVITY					Negative		

TABLE 2: Ames Salmonella Mutagenicity Test Results for Inco Corning filter:

Tester strain TA98 without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS			MEAN	STD. +/-	NET REV.
3000	-	1145[T]	1210[T]	1544[T]	1300[T]	214	1278
1800	-	1177	1339	1242	1253	82	1231
1500	-	940	1123	994	1019	94	997
1200	-	746	770	834	783	45	761
900	-	628	714	646	663	45	641
600	-	390	474	450	438	43	416
300	-	197	231	305	244	55	222
150	-	127	121	134	127	7	105
NEGATIVE CONTROL	-	28	30	20 15 17	22	6	
HISTORICAL CONTROL	-				26		
POSITIVE CONTROL	-	565		578 586	576	11	
HISTORICAL CONTROL	-				684		
2NF 2µg SPECIFIC ACTIVITY	.				0.64		

T = slight toxicity.

Tester strain TA98NR without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS			MEAN	STD. +/-	NET REV.
3000	-	614[T]	497[T]	567[T]	559[T]	59	541
1800	-	521	492	553	522	31	304
1500	-	590	573	594	586	11	567
1200	-	492	472	591	518	64	500
900	-	418	398	452	423	27	404
600	-	335	296	270	300	33	282
300	-	176	164	173	171	6	153
150	-	85	89	83	86	3	67
NEGATIVE CONTROL	-	21	24	17 17 18	18	5	
HISTORICAL CONTROL	-				17		
POSITIVE CONTROL	-	79		95 84	86	8	
HISTORICAL CONTROL	-				76		
2NF 2µg SPECIFIC ACTIVITY					0.41		

T = slight toxicity

TABLE 2 (Con't):

Tester strain TA98/1,8DNP$_6$ without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	MISTIDINE REVERTANTS			MEAN	STD. +/-	NET REV.
3000	-	47^T	65^T	60^T	57^T	9	36
1800	-	62^T	61^T	80^T	68^T	11	47
1500	-	71	80	70	74	6	53
1200	-	86	81	63	77	12	56
900	-	72	71	83	75	7	54
600	-	69	71	70	70	1	49
300	-	48	43	52	48	5	27
150	-	40	42	38	40	2	19
NEGATIVE CONTROL	-	26	17	20 22 20	21	3	
HISTORICAL CONTROL	-				15		
POSITIVE CONTROL	-	71		81 76	76	5	
HISTORICAL CONTROL	-				81		
2NF 2µg SPECIFIC ACTIVITY					0.04		

T = slight toxicity

TABLE 2A: Ames Salmonella Mutagenicity Test Results for Inco Corning filter:
Tester strain TA98 without metabolic activiation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS	MEAN	STD. +/-	NET REV.
2000	-	278 326 337	312	35	275
1400	-	278 252 268	266	13	230
1000	-	154 175 152	160	13	124
600	-	116 150 132	133	17	96
500	-	131 126 166	141	22	105
400	-	105 107 125	112	11	76
300	-	109 129 113	117	11	81
200	-	89 82 109	93	14	57
100	-	75 77 80	77	3	41
50	-	78 68 54	67	12	30
NEGATIVE CONTROL	-	29 30 49 41 32	36	8	
HISTORICAL CONTROL	-		31		
POSITIVE CONTROL	-	460 483 487	477	15	
HISTORICAL CONTROL	-		580		
2NF 2µg SPECIFIC ACTIVITY			0.13		

Tester strain TA98NR without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS	MEAN	STD. +/-	NET REV.
2000	-	154 141 143	146	7	131
1400	-	125 145 118	129	14	114
1000	-	91 66 63	73	15	58
600	-	44 57 49	50	7	35
500	-	60 60 59	60	1	44
400	-	45 48 59	51	7	35
300	-	50 45 68	54	12	39
200	-	38 37 43	39	3	24
100	-	33 38 21	31	9	15
50	-	31 31 36	33	3	17
NEGATIVE CONTROL	-	14 23 17 15 7	15	5	
HISTORICAL CONTROL	-		16		
POSITIVE CONTROL	-	83 68 64	72	10	
HISTORICAL CONTROL	-		74		
2NF 2µg SPECIFIC ACTIVITY			0.06		

TABLE 2A (Con't):

Tester strain TA98/1,8DNP$_6$ without metabolic activation

CONCENTRATION µG/PLATE	S-9 MIX	HISTIDINE REVERTANTS			MEAN	STD. +/-	NET REV.
2000	-	40	38	33	37	4	23
1400	-	35	39	40	38	3	24
1000	-	26	12	18	19	7	5
600	-	21	27	25	24	3	11
500	-	24	23	24	24	1	10
400	-	22	29	31	27	5	14
300	-	23	27	31	27	4	13
200	-	27	25	33	28	4	15
100	-	25	22	14	20	6	7
50	-	27	23	28	26	3	12
NEGATIVE CONTROL	-	10	9	15 16 18	14	3	
HISTORICAL CONTROL	-				15		
POSITIVE CONTROL	-	38		56 47	47	9	
HISTORICAL CONTROL	-				64		
2NF 2µg SPECIFIC ACTIVITY					Negative		

TABLE 3: Ames Salmonella Mutagenicity Test Results for Inco PTX catalyst:

Tester strain TA98 without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS			MEAN	STD. +/-	NET REV.
1000	-	286	265	309	287	22	265
600	-	183	207	213	201	16	180
500	-	160	209	201	190	26	169
400	-	206	201	180	196	14	174
300	-	170	191	170	177	12	156
200	-	140	142	106	129	20	108
100	-	102	89	93	95	7	73
50	-	81	65	66	71	9	49
NEGATIVE CONTROL	-	23	17	20 23 23	21	2	
HISTORICAL CONTROL	-				26		
POSITIVE CONTROL	-	479		382 437	433	49	
HISTORICAL CONTROL	-				507		
2NF 2µg							
SPECIFIC ACTIVITY					0.41		

Tester strain TA98NR without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS			MEAN	STD. +/-	NET REV.
1000	-	102	127	118	116	13	100
600	-	106	98	83	96	12	80
500	-	122	101	97	107	13	91
400	-	96	91	85	91	6	75
300	-	77	85	87	83	5	68
200	-	60	76	55	64	11	48
100	-	46	47	46	46	1	31
50	-	34	38	29	34	5	18
NEGATIVE CONTROL	-	20	21	13 11 12	15	5	
HISTORICAL CONTROL	-				16		
POSITIVE CONTROL	-	56		67 75	66	10	
HISTORICAL CONTROL	-				70		
2NF 2µg							
SPECIFIC ACTIVITY					0.19		

TABLE 3 (Con't):

Tester strain TA98/1,DNP_6 without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS					MEAN	STD. +/-	NET REV.
1000	-	40	36	37			38	2	23
600	-	50	37	30			39	10	24
500	-	35	45	40			40	5	25
400	-	47	47	42			45	3	30
300	-	45	47	39			44	4	29
200	-	45	45	39			43	3	28
100	-	31	22	22			25	5	10
50	-	26	22	19			22	4	7
NEGATIVE CONTROL	-	23	11	18	6	17	15	6	
HISTORICAL CONTROL	-						15		
POSITIVE CONTROL	-	98		84		77	86	11	
HISTORICAL CONTROL	-						75		
2NF 2µg SPECIFIC ACTIVITY							Negative		

TABLE 3A: Ames Salmonella Mutagenicity Test Results for Inco PTX catalyst:
Tester strain TA98 without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS			MEAN	STD. +/-	NET REV.
2000	-	501[T]	489[T]	544[T]	511[T]	29	485
1400	-	476[T]	432[T]	485[T]	464[T]	28	438
1000	-	288[T]	303[T]	276[T]	289[T]	14	263
600	-	243	234	185	221	31	194
500	-	185	178	215	193	20	166
400	-	181	189	210	193	15	167
300	-	211	211	166	196	26	170
200	-	156	116	134	136	20	109
100	-	113	116	121	117	4	90
50	-	37	33	43	38	5	11
NEGATIVE CONTROL	-	29	22	35 26 20	26	5	
HISTORICAL CONTROL	-				26		
POSITIVE CONTROL	-	503		625 503	544	70	
HISTORICAL CONTROL	-				526		
2NF 2µg							
SPECIFIC ACTIVITY					0.40		

T = slight toxicity

Tester strain TA98NR without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS			MEAN	STD. +/-	NET REV.
2000	-	208	204	228	213	13	189
1400	-	193	211	213	206	11	181
1000	-	133	118	154	135	18	110
600	-	125	112	91	109	17	85
500	-	95	94	118	102	14	78
400	-	78	87	78	81	5	56
300	-	82	68	80	77	8	52
200	-	43	48	48	46	3	22
100	-	41	46	26	38	10	13
50	-	19	18	13	17	3	-8
NEGATIVE CONTROL	-	26	21	25 27 24	25	2	
HISTORICAL CONTROL	-				21		
POSITIVE CONTROL	-	122		118 139	126	11	
HISTORICAL CONTROL	-				98		
2NF 2µg							
SPECIFIC ACTIVITY					0.20		

TABLE 3A (Con't):

Tester strain TA98/1,8DNP$_6$ without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS			MEAN	STD. +/-	NET REV.
2000	-	0 Tox	0 Tox	6 Tox	2 Tox	3	-12
1400	-	0 Tox	0 Tox	6 Tox	2 Tox	3	-12
1000	-	16^T	17^T	33T	22^T	10	8
600	-	27	34	36	32^T	5	18
500	-	4	31	51	29^T	24	14
400	-	38	54	49	47	8	33
300	-	13	28	17	19	8	5
200	-	11	25	25	20	8	6
100	-	17	27	20	21	5	7
50	-	22	8	11	14	7	-1
NEGATIVE CONTROL	-	5	15 19	13 20	14	5	
HISTORICAL CONTROL	-				15		
POSITIVE CONTROL	-	57	54	92	68	21	
HISTORICAL CONTROL	-				72		
2NF 2µg SPECIFIC ACTIVITY					Negative		

T = slight toxicity

TABLE 4: Ames Salmenella Mutagenicity Test Results for Falconbridge bare engine:

Tester strain TA98 without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS					MEAN	STD. +/-	NET REV.
1000	-	120	116	109			115	6	90
600	-	92	92	94			93	1	68
500	-	140	94	95			110	26	85
400	-	101	101	118			107	10	82
300	-	104	98	96			99	4	75
200	-	90	98	76			88	11	63
100	-	57	53	65			58	6	34
50	-	33	57	66			52	17	27
NEGATIVE CONTROL	-	18	30	25	30	20	25	5	
HISTORICAL CONTROL	-						26		
POSITIVE CONTROL	-	640		521		558	573	60	
HISTORICAL CONTROL	-						550		
2NF 2µg SPECIFIC ACTIVITY							0.20		

Tester strain TA98NR without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS					MEAN	STD. +/-	NET REV.
1000	-	48	45	62			52	9	36
600	-	42	41	52			45	6	30
500	-	59	61	54			58	4	43
400	-	42	51	70			54	14	39
300	-	42	54	42			46	7	31
200	-	43	23	44			37	12	21
100	-	36	38	36			37	1	21
50	-	22	27	23			24	3	9
NEGATIVE CONTROL	-	20	21	13	11	12	15	5	
HISTORICAL CONTROL	-						16		
POSITIVE CONTROL	-	56		67		75	66	10	
HISTORICAL CONTROL	-						70		
2NF 2µg SPECIFIC ACTIVITY							.07		

TABLE 4 (Con't):

Tester strain TA98/1,8DNP$_6$ without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS			MEAN	STD. +/-	NET REV.
1000	-	19	19	10	16	5	1
600	-	24	11	20	18	7	3
500	-	24	28	26	26	2	11
400	-	30	18	23	24	6	9
300	-	21	32	25	26	6	11
200	-	41	31	29	27	5	12
100	-	19	37	25	27	9	12
50	-	18	17	29	21	7	6
NEGATIVE CONTROL	-	23	11 18	6 18	15	6	
HISTORICAL CONTROL	-				15		
POSITIVE CONTROL	-	98	84	77	86	11	
HISTORICAL CONTROL	-				75		
2NF 2µg SPECIFIC ACTIVITY					Negative		

TABLE 4A: Ames Salmonella Mutagenicity Test Results for Falconbridge bare engine:
Tester strain TA98 without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS			MEAN	STD. +/-	NET REV.
2000	-	141	156	127	141	15	115
1400	-	110	116	141	122	16	96
1000	-	94	68	100	87	17	61
600	-	87	101	66	85	18	58
500	-	75	81	72	76	5	50
400	-	95	68	66	76	16	50
300	-	72	48	72	64	14	38
200	-	64	60	58	61	3	34
100	-	64	48	51	54	9	28
50	-	30	32	45	36	8	9
NEGATIVE CONTROL	-	29	22	35 26 20	26	5	
HISTORICAL CONTROL	-				26		
POSITIVE CONTROL	-	503		625 503	544	70	
HISTORICAL CONTROL	-				526		
2NF 2µg							
SPECIFIC ACTIVITY					0.10		

Tester strain TA98NR without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS			MEAN	STD. +/-	NET REV.
2000	-	49	48	56	51	4	26
1400	-	54	39	60	51	11	26
1000	-	44	34	42	40	5	15
600	-	46	47	47	47	1	22
500	-	32	32	31	32	1	7
400	-	36	41	42	40	3	15
300	-	34	37	45	39	6	14
200	-	36	45	47	43	6	18
100	-	29	49	39	39	10	14
50	-	43	36	44	41	4	16
NEGATIVE CONTROL	-	26	21	25 27 24	25	2	
HISTORICAL CONTROL	-				21		
POSITIVE CONTROL	-	122		118 139	126	11	
HISTORICAL CONTROL	-				98		
2NF 2µg							
SPECIFIC ACTIVITY					Negative		

TABLE 4A (Con't):

Tester strain TA98/1,8DNP$_6$ without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS			MEAN	STD. +/-	NET REV.
2000	-	Toxicity			Tox		
1400	-	Tox	11	Tox	Tox		
1000	-	1^T	3^T	3^T	2^T	1	-12
600	-	6	1	4	4	3	-11
500	-	4	Tox	9	4	5	-10
400	-	14	Tox	16	10	9	-4
300	-	6^T	2^T	8^T	5	3	-9
200	-	13	21	18	17	4	3
100	-	18	19	23	20	3	6
50	-	15	7	13	12	4	-3
NEGATIVE CONTROL	-	5	15 19	13 20	14	5	
HISTORICAL CONTROL	-				15		
POSITIVE CONTROL	-	57	54	92	68	21	
HISTORICAL CONTROL	-				72		
2NF 2µg SPECIFIC ACTIVITY					Negative		

T = slight toxicity

TABLE 5: Ames Salmonella Mutagenicity Test Results for Falconbridge Johnson Mathey catalyst:

Tester strain TA98 without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS					MEAN	STD. +/-	NET REV.
1000	-	87	111	137			112	25	87
600	-	134	123	125			127	6	103
500	-	138	111	109			119	16	95
400	-	100	118	139			119	20	94
300	-	102	110	101			104	5	80
200	-	93	87	88			89	3	65
100	-	65	57	65			62	5	38
50	-	54	50	44			49	5	25
NEGATIVE CONTROL	-	18	30	25	30	20	25	5	
HISTORICAL CONTROL	-						26		
POSITIVE CONTROL	-	640		521		558	573	61	
HISTORICAL CONTROL	-						550		
2NF 2µg SPECIFIC ACTIVITY							0.22		

Tester strain TA98NR without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS					MEAN	STD. +/-	NET REV.
1000	-	61	78	67			69	9	53
600	-	42	40	61			48	12	32
500	-	49	48	57			51	5	36
400	-	49	46	58			51	6	36
300	-	54	46	36			45	9	30
200	-	43	34	45			41	6	25
100	-	32	24	29			28	4	13
50	-	28	21	28			26	4	10
NEGATIVE CONTROL	-	20	21	13	11	12	15	5	
HISTORICAL CONTROL	-						16		
POSITIVE CONTROL	-	56		67		75	66	10	
HISTORICAL CONTROL	-						70		
2NF 2µg SPECIFIC ACTIVITY							Negative		

TABLE 5A

(Repeat)

Ames Salmonella Mutagenicity Test Results for Falconbridge Johnson Mathey catalyst:

Tester strain TA98 without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS			MEAN	STD. +/-	NET REV.
2000	-	223	205	241	223	18	202
1400	-	220	179	146	182	37	161
1000	-	106	142	144	131	21	110
600	-	94	120	143	119	25	98
500	-	120	127	120	122	4	102
400	-	118	113	106	112	6	92
300	-	112	105	121	113	8	92
200	-	103	92	104	100	7	79
100	-	67	69	83	73	9	52
50	-	43	46	55	48	6	27
NEGATIVE CONTROL	-	19	13 30	24 17	21	6	
HISTORICAL CONTROL	-				24		
POSITIVE CONTROL	-	683	591	742	672	76	
HISTORICAL CONTROL	-				611		
2NF 2µg SPECIFIC ACTIVITY					0.25		

TABLE 5 (Con't):

Tester strain TA98/1,8DNP$_6$ without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS			MEAN	STD. +/-	NET REV.
1000	-	37	39	23	33	9	18
600	-	23	26	23	24	2	9
500	-	29	25	27	27	2	12
400	-	18	20	27	22	5	7
300	-	29	24	19	24	5	9
200	-	25	21	27	24	3	9
100	-	23	30	20	24	5	9
50	-	17	20	31	23	7	8
NEGATIVE CONTROL	-	23 11	18 6	17	15	6	
HISTORICAL CONTROL	-				15		
POSITIVE CONTROL	-	98	84	77	86	11	
HISTORICAL CONTROL	-				75		
2NF 2µg							
[illegible] ACTIVITY					Negative		

TABLE 5A: Ames Salmonella Mutagenicity Test Results for Falconbridge Johnson Mathey catalyst:

Tester strain TA98 without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS			MEAN	STD. +/-	NET REV.
2000	-	178[T]	202[T]	153[T]	178[T]	25	151
1400	-	160[T]	137[T]	149[T]	149[T]	12	122
1000	-	105	119	91	105	14	79
600	-	113	96	74	94	20	68
500	-	92	82	77	84	8	57
400	-	74	81	74	76	4	50
300	-	78	67	89	78	11	52
200	-	73	56	62	64	9	37
100	-	49	53	57	53	4	27
50	-	29	28	41	33	7	6
NEGATIVE CONTROL	-	29	22	35 26 20	26	5	
HISTORICAL CONTROL	-				26		
POSITIVE CONTROL	-	503		625 503	544	70	
HISTORICAL CONTROL	-				526		
2NF 2µg SPECIFIC ACTIVITY					0.17		

T = slight toxicity

Tester strain TA98NR without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS			MEAN	STD. +/-	NET REV.
2000	-	80[T]	88[T]	77[T]	82[T]	6	57
1400	-	77	70	66	71	6	46
1000	-	55	54	57	55	2	31
600	-	48	51	45	48	3	23
500	-	43	42	42	42	1	18
400	-	34	40	44	39	5	15
300	-	54	55	35	48	11	23
200	-	48	59	41	49	9	25
100	-	44	45	48	46	2	21
50	-	29	38	49	39	10	14
NEGATIVE CONTROL	-	26	21	25 27 24	25	2	
HISTORICAL CONTROL	-				21		
POSITIVE CONTROL	-	122		118 139	126	11	
HISTORICAL CONTROL	-				98		
2NF 2µg SPECIFIC ACTIVITY					Negative		

T = slight toxicity

TABLE 5A (Con't):

Tester strain TA98/1,8DNP$_6$ without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS			MEAN	STD. +/-	NET REV.
2000	-	26	27	24	26	2	11
1400	-	30	34	17	27	9	13
1000	-	20	16	14	17	3	2
600	-	15	13	21	16	4	2
500	-	15	19	23	19	4	5
400	-	19	13	9	14	5	-1
300	-	23	8	14	15	8	1
200	-	12	24	21	19	6	5
100	-	19	19	12	17	4	2
50	-	16	14	17	16	2	1
NEGATIVE CONTROL	-	5	15 19	13 20	14	5	
HISTORICAL CONTROL	-				15		
POSITIVE CONTROL	-	57	54	92	68	21	
HISTORICAL CONTROL	-				72		
2NF 2µg SPECIFIC ACTIVITY					Negative		

TABLE 6: Ames Salmonella Mutagenicity Test Results for Falconbridge fume diluter:

Tester strain TA98 without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS			MEAN	STD. +/-	NET REV.
1000	-	97	113	95	102	10	77
600	-	92	93	80	88	7	64
500	-	90	94	96	93	3	69
400	-	82	122	72	92	26	67
300	-	92	101	84	92	9	68
200	-	71	63	75	70	6	45
100	-	60	54	45	53	8	28
50	-	30	56	36	41	14	16
NEGATIVE CONTROL	-	18	30	25 30 20	25	5	
HISTORICAL CONTROL	-				26		
POSITIVE CONTROL	-	640		521 558	573	61	
HISTORICAL CONTROL	-				550		
2NF 2µg SPECIFIC ACTIVITY					0.20		

Tester strain TA98NR without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS			MEAN	STD. +/-	NET REV.
1000	-	57	48	64	56	8	41
600	-	57	46	35	46	11	31
500	-	45	53	37	45	8	30
400	-	43	50	50	48	4	32
300	-	63	48	56	56	8	40
200	-	35	48	28	37	10	22
100	-	42	35	39	39	4	23
50	-	34	21	24	26	7	11
NEGATIVE CONTROL	-	20	21	13 11 12	15	5	
HISTORICAL CONTROL	-				18		
POSITIVE CONTROL	-	56		67 75	66	10	
HISTORICAL CONTROL	-				70		
2NF 2µg SPECIFIC ACTIVITY					0.10		

TABLE 6 (Con't):

Tester strain TA98/1,8DNP$_6$ without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS	MEAN	STD. +/-	NET REV.
1000	-	28 32 35	32	4	17
600	-	23 27 23	24	2	9
500	-	35 37 27	33	5	18
400	-	32 32 41	35	5	20
300	-	25 26 33	28	4	13
200	-	28 26 34	29	4	14
100	-	23 26 32	27	5	12
50	-	25 16 20	20	5	5
NEGATIVE CONTROL	-	23 11 18 6 17	15	6	
HISTORICAL CONTROL	-		15		
POSITIVE CONTROL	-	98 84 77	86	11	
HISTORICAL CONTROL	-		75		
2NF 2µg SPECIFIC ACTIVITY			Negative		

TABLE 6A: Ames Salmonella Mutagenicity Test Results for Falconbridge fume diluter: Tester strain TA98 without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS			MEAN	STD. +/-	NET REV.
2000	-	215	211	228	218	9	182
1400	-	204	144	193	180	32	144
1000	-	111	130	111	117	11	81
600	-	90	128	93	104	21	67
500	-	105	103	91	100	8	63
400	-	98	94	90	94	4	58
300	-	106	66	88	87	20	50
200	-	78	84	72	78	6	42
100	-	70	72	76	73	3	36
50	-	55	51	46	51	5	14
NEGATIVE CONTROL	-	29	30	49 41 32	36	8	
HISTORICAL CONTROL	-				31		
POSITIVE CONTROL	-	460		483 487	477	15	
HISTORICAL CONTROL	-				580		
2nd 2_{up} SPECIFIC ACTIVITY					0.13		

Tester strain TA98NR without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS			MEAN	STD. +/-	NET REV.
2000	-	76	79	79	78	2	63
1400	-	66	74	71	70	4	55
1000	-	29	55	56	47	15	31
600	-	48	29	47	41	11	26
500	-	41	29	35	35	6	20
400	-	27	35	48	37	11	21
300	-	31	40	34	35	5	20
200	-	32	41	36	36	5	21
100	-	34	29	31	31	3	16
50	-	35	40	35	37	3	21
NEGATIVE CONTROL	-	14	23	17 15 7	15	5	
HISTORICAL CONTROL	-				16		
POSITIVE CONTROL	-	83		68 64	72	10	
HISTORICAL CONTROL	-				74		
2nd 2_{up} SPECIFIC ACTIVITY					Negative		

TABLE 6A (Con't):

Tester strain TA98/1,8DNP$_6$ without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS	MEAN	STD. +/-	NET REV.
2000	-	15 Tox 23 Tox 17 Tox	18	4	5
1400	-	28 28 Tox 23	26	3	13
1000	-	22 24 20	22	2	8
600	-	26 15 17	19	6	6
500	-	21 18 19	19	2	6
400	-	16 22 20	19	3	6
300	-	29 33 34	32	3	18
200	-	23 28 19	23	5	10
100	-	35 28 20	28	8	14
50	-	21 21 9	17	7	3
NEGATIVE CONTROL	-	10 9 15 16 18	14	3	
HISTORICAL CONTROL	-		15		
POSITIVE CONTROL	-	38 56 47	47	9	
HISTORICAL CONTROL	-		64		
2NF 2µg SPECIFIC ACTIVITY			Negative		

TABLE 7: Ames Salmonella Mutagenicity Test Results for Falconbridge fume diluter plus catalyst:

Tester strain TA98 without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS			MEAN	STD. +/-	NET REV.
2000	-	234	230	195	220	21	199
1400	-	201	163	232	199	35	178
1000	-	147	187	138	157	26	137
600	-	148	281	103	177	93	157
500	-	133	120	103	119	15	98
400	-	100	115	129	115	15	94
300	-	108	94	94	99	8	78
200	-	87	94	65	82	15	61
100	-	62	60	68	63	4	43
50	-	35	43	32	37	6	16
NEGATIVE CONTROL	-	19	13	30 24 17	21	6	
HISTORICAL CONTROL	-				24		
POSITIVE CONTROL	-	683		591 742	672	76	
HISTORICAL CONTROL	-				611		
2NF 2µg							
SPECIFIC ACTIVITY					0.21		

Tester strain TA98NR without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS			MEAN	STD. +/-	NET REV.
2000	-	81	77	99	86	12	68
1400	-	71	98	70	80	16	62
1000	-	53	74	66	64	11	47
600	-	59	63	73	65	7	47
500	-	42	70	47	53	15	35
400	-	67	61	54	61	7	43
300	-	44	47	36	42	6	25
200	-	46	36	50	44	7	26
100	-	41	35	23	33	9	15
50	-	20	23	24	22	2	5
NEGATIVE CONTROL	-	25	23	20 11 10	18	7	
HISTORICAL CONTROL	-				20		
POSITIVE CONTROL	-	82		85 86	84	2	
HISTORICAL CONTROL	-				91		
2NF 2µg							
SPECIFIC ACTIVITY					0.09		

TABLE 7 (Con't):

Tester strain TA98/1,8DNP$_6$ without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS			MEAN	STD. +/-	NET REV.
2000	-	38	38	38	38	0	21
1400	-	30	43	45	39	8	22
1000	-	32	28	40	33	6	16
600	-	39	32	33	35	4	17
500	-	39	29	38	32	6	15
400	-	26	20	34	27	7	9
300	-	30	33	23	29	5	11
200	-	24	21	21	22	2	5
100	-	28	20	32	27	6	9
50	-	14	18	13	15	3	-2
NEGATIVE CONTROL	-	16	14	16	19	22	17	3	
HISTORICAL CONTROL	-						16		
POSITIVE CONTROL	-	82		82		88	84	3	
HISTORICAL CONTROL	-						78		
2NF 2µg									
SPECIFIC ACTIVITY							negative		

TABLE 7A: Ames Salmonella Mutagenicity Test Results for Falconbridge fume diluter plus catalyst:

Tester strain TA98 without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS					MEAN	STD. +/-	NET REV.
2000	-	254		216		217	229	22	203
1400	-	212		206		231	216	13	190
1000	-	141		175		146	154	18	128
600	-	124		145		119	129	14	103
500	-	116		98		133	116	18	89
400	-	91		125		108	108	17	82
300	-	105		117		93	105	12	79
200	-	97		75		86	86	11	60
100	-	61		65		76	67	8	41
50	-	26		36		34	32	5	6
NEGATIVE CONTROL	-	29	22	35	26	20	26	5	
HISTORICAL CONTROL	-						26		
POSITIVE CONTROL	-	503		625		503	544	70	
HISTORICAL CONTROL	-						526		
2NF 2µg									
SPECIFIC ACTIVITY							0.20		

Tester strain TA98NR without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS					MEAN	STD. +/-	NET REV.
2000	-	110		99		115	108	8	83
1400	-	103		109		123	112	10	87
1000	-	96		79		67	81	15	56
600	-	57		78		69	68	11	43
500	-	43		77		63	61	17	36
400	-	64		71		61	65	5	41
300	-	64		49		66	60	9	35
200	-	47		57		59	54	6	30
100	-	62		60		55	59	4	34
50	-	32		37		44	38	6	13
NEGATIVE CONTROL	-	26	21	25	27	24	25	2	
HISTORICAL CONTROL	-						21		
POSITIVE CONTROL	-								
HISTORICAL CONTROL	-	122		118		139	126	11	
2NF 2µg							98		
SPECIFIC ACTIVITY							0.04		

TABLE 7A (Con't):

Tester strain TA98/1,8DNP$_6$ without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS	MEAN	STD. +/-	NET REV.
2000	-	13 Tox TOXICITY	TOX		
1400	-	24 T 15 T 21 T	20 T	5	6
1000	-	Tox 22 16	13	11	-2
600	-	5 15 7	9	5	-5
500	-	7 11 9	9	2	-5
400	-	3 1 16	7	8	-8
300	-	2 9 1	4	4	-10
200	-	8 5 13	9	4	-6
100	-	2 1 1	1	1	-13
50	-	2 2 2	2	0	-12
NEGATIVE CONTROL	-	5 15 19 13 20	14	5	
HISTORICAL CONTROL	-		15		
POSITIVE CONTROL	-	57 54 92	68	21	
HISTORICAL CONTROL	-		72		
2NF 2µg SPECIFIC ACTIVITY			negative		

T slight toxicity

TABLE 8: Ames Salmonella Mutagenicity Test Results for (J23 Resin + J24 + J25 Resins). Inco corning filter resins:

Tester strain TA98 without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS	MEAN	STD. +/-	NET REV.
600	-	160	160	-	135
500	-	144	144	-	119
400	-	154	154	-	129
300	-	125	125	-	100
200	-	92	92	-	67
100	-	65	65	-	40
NEGATIVE CONTROL	-	18 30 25 30 20	25	5	
HISTORICAL CONTROL	-		26		
POSITIVE CONTROL	-	558 521 641	573	62	
HISTORICAL CONTROL	-		550		
2NF 2µg SPECIFIC ACTIVITY			0.3		

TABLE 9: Ames Salmonella Mutagenicity Test Results for J11 Resin + J13 resin:

Tester strain TA98 without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS	MEAN	STD. +/-	NET REV.
1000	-	175	175	-	150
600	-	140	140	-	115
500	-	140	140	-	115
400	-	123	123	-	98
300	-	96	96	-	71
200	-	98	98	-	73
100	-	64	64	-	39
NEGATIVE CONTROL	-	18 30 25 30 20	25	5	
HISTORICAL CONTROL	-		26		
POSITIVE CONTROL	-	558 521 641	573	62	
HISTORICAL CONTROL	-		526		
2NF 2µg SPECIFIC ACTIVITY			0.18		

TABLE 10: Ames Salmonella Mutagenicity Test Results for J19 AE Resin: Tester strain TA98 without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS					MEAN	STD. +/-	NET REV.
500	-	83				94	89	8	55
400	-	90				82	86	6	52
300	-	79				94	87	11	53
200	-	76				69	73	5	39
100	-	72				51	62	15	28
NEGATIVE CONTROL	-	26	19	29	43	53	34	12	
HISTORICAL CONTROL	-						29		
POSITIVE CONTROL	-	539		508		556	534	24	
HISTORICAL CONTROL	-						573		
2NF 2µg									
SPECIFIC ACTIVITY							negative		

TABLE 11: Ames Salmonella Mutagenicity Test Results for D13 Resin + D15 Resin: Tester strain TA98 without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS					MEAN	STD. +/-	NET REV.
1000	-	41					41	-	16
600	-	34		37		33	35	2	10
500	-	45		50		33	43	9	18
400	-	28		48		29	35	11	10
300	-	52		33		47	44	10	19
200	-	28		32		38	33	5	8
100	-	38		39		43	40	3	15
NEGATIVE CONTROL	-	18	30	25	30	20	25	5	
HISTORICAL CONTROL	-						26		
POSITIVE CONTROL	-	558		521		641	573	62	
HISTORICAL CONTROL	-						550		
2NF 2µg									
SPECIFIC ACTIVITY							negative		

TABLE 12: Ames Salmonella Mutagenicity Test Results for D22 + 30 Resins:

Tester strain TA98 without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS					MEAN	STD. +/-	NET REV.
1000	-	53		59		59	57	3	36
600	-	45		54		51	50	5	29
500	-	40		39		53	44	8	23
400	-	57		43		48	49	7	29
300	-	44		39		47	43	4	23
200	-	41		33		54	43	11	22
100	-	46		29		36	37	9	16
50	-	25		31		41	32	8	12
NEGATIVE CONTROL	-	23	25	13	21	22	21	4	
HISTORICAL CONTROL	-						25		
POSITIVE CONTROL	-	624		579		426	543	104	
HISTORICAL CONTROL	-						558		
2NF 2µg SPECIFIC ACTIVITY							negative		

TABLE 13: Ames Salmonella Mutagenicity Test Results for Inco corning trap repeat filter:

Tester strain TA98 without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS					MEAN	STD. +/-	NET REV.
600	-	14		20		19	18	3	-16
500	-	29		32		21	27	6	-6
400	-	33		28		21	27	6	-6
300	-	25		34		22	27	6	-6
200	-	36		17		20	24	10	-9
100	-	21		33		19	24	8	-9
50	-	26		29		29	28	2	-5
25	-	28		36		33	32	4	-1
NEGATIVE CONTROL	-	33	29	38	34	32	33	3	
HISTORICAL CONTROL	-						29		
POSITIVE CONTROL	-	623		627		650	633	15	
HISTORICAL CONTROL							596		
2NF 2µg SPECIFIC ACTIVITY							negative		

TABLE 13 (Con't):

Tester strain TA98NR without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS					MEAN	STD. +/-	NET REV.
600	-	17		17		18	17	1	-6
500	-	21		19		21	20	1	-3
400	-	20		20		11	17	5	-6
300	-	17		21		23	20	3	-3
200	-	16		17		16	16	1	-7
100	-	8		18		9	12	6	-12
50	-	22		19		18	20	2	-4
25	-	6		6		25	12	11	-11
NEGATIVE CONTROL	-	21	24	22	23	27	23	2	
HISTORICAL CONTROL	-								
POSITIVE CONTROL	-	66		82		74	74	8	
HISTORICAL CONTROL	-						83		
2NF 2µg SPECIFIC ACTIVITY							negative		

Tester strain TA98/1,8DNP$_6$ without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS					MEAN	STD. +/-	NET REV.
600	-	TOXICITY					TOX		
500	-	2		3		2	2	1	-6
400	-	1		2		0	1	1	-8
300	-	0		4		1	2	2	-7
200	-	6		5		3	5	2	-4
100	-	6		3		1	3	3	-5
50	-	2		4		9	5	4	-4
25	-	6		9		7	7	2	-1
NEGATIVE CONTROL	-	5	10	11	14	3	9	4	
HISTORICAL CONTROL	-						13		
POSITIVE CONTROL	-	27		17		26	23	6	
HISTORICAL CONTROL	-						51		
2NF 2µg SPECIFIC ACTIVITY							negative		

TABLE 14: Ames Salmonella Mutagenicity Test Results for Inco corning trap repeat filter:

Tester strain TA98 without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS	MEAN	STD. +/-	NET REV.
10,000	-	155 157 151	154	3	121
8,000	-	125 132 137	131	6	98
6,000	-	104 104 101	103	2	70
4,000	-	122 106 125	118	10	84
2,000	-	84 97 82	88	8	54
NEGATIVE CONTROL	-	33 29 38 34 32	33	3	
HISTORICAL CONTROL	-		29		
POSITIVE CONTROL	-	623 627 650	633	15	
HISTORICAL CONTROL	-		596		
2NF 2µg SPECIFIC ACTIVITY			0.013		

TABLE 15: Ames Salmonella Mutagenicity Test Results for Inco corning trap repeat resin:

Tester strain TA98 without metabolic activation

CONCENTRATION µg/PLATE	S-9 MIX	HISTIDINE REVERTANTS	MEAN	STD. +/-	NET REV.
600	-	102 104	103	1	70
500	-	99 74	87	18	53
400	-	62 86	74	17	41
300	-	63 64	64	1	30
200	-	58 - 40	49	13	16
100	-	35 43	39	6	6
50	-	44 38	41	4	8
25	-	35 30	33	4	-1
NEGATIVE CONTROL	-	33 29 38 34 32	33	3	
HISTORICAL CONTROL	-		29		
POSITIVE CONTROL	-	623 627 650	633	15	
HISTORICAL CONTROL	-		596		
2NF 2µg SPECIFIC ACTIVITY			0.13		

Table 16: Ames Salmonella Mutagenicity Test Results for Inco Corning Filter Trap using tester strain TA-98 without metabolic activation. (HF #A25 Left Hi Vol #1 and 2)

Concentration µg/plate	S-9 Mix	Histidine Revertants	Mean	Std. Dev. +/-	Net Rev.
3000	-	481 534 408 sl.tox	474	63	454
2700	-	454 472 467	464	9	444
2400	-	430 401 432	421	17	420
2100	-	371 329 310	337	31	317
1800	-	359 314 280	318	40	298
1500	-	287 326 253	289	37	269
1200	-	336 263 272	290	40	270
900	-	298 291 316	302	13	282
600	-	251 231 166	216	44	196
300	-	150 148 156	151	4	131
150	-	92 110 99	100	9	80
Negative Control	-	19 21 20 22 19	20		
Historical Control	-		22		
Positive Control	-	688 515 626	610		
Historical Control	-		611		
2NF 2 µg Specific Activity			0.26		

2NF - 2-nitrofluorene

sl.tox - slight toxicity

Soluble organic Fraction (SOF) = 284.3 mg

Table 17: Ames Salmonella Mutagenicity Test Results for Inco Corning Filter Trap using tester strain TA-98 without metabolic activation. (HF #J5 Left Hi Vol #1 and 2).

Concentration µg/plate	S-9 Mix	Histidine Revertants	Mean	Std.Dev. +/-	Net. Rev.
3000	-	273 269 273 sl.tox	272	2	252
2700	-	251 265 252	256	8	236
2400	-	251 241 206	233	24	213
2100	-	197 205 206	203	5	183
1800	-	177 206 176	186	17	166
1500	-	185 166 194	182	14	162
1200	-	145 163 156	155	8	135
900	-	191 219 144	185	38	165
600	-	128 139 135	134	6	114
300	-	102 84 80	89	12	69
150	-	70 57 46	58	12	38
Negative Control	-	19 21 20 22 19	20		
Historical Control	-		22		
Positive Control	-	688 515 626	610		
Historical Control	-		611		
2NF 2 µg Specific Activity			0.17		

2NF - 2-nitrofluorene

sl.tox - slight toxicity

Soluble organic fraction (SOF) = 358.9 mg

Table 18: Ames Salmonella Mutagenicity Test Results for Inco Corning Filter Trap using tester strain TA-98 without metabolic activation. (HF #M7 Left Filter #1)

Concentration µg/plate	S-9 Mix	Histidine Revertants	Mean	Std. Dev. +/-	Net Rev.
3000	-	896 1123 788 sl.tox	936	171	916
2700	-	1048 886 1145 sl.tox	1026	131	1006
2400	-	896 929 1037 sl.tox	954	74	934
2100	-	972 1048 886	969	81	949
1800	-	1123 1750 1231	1368	335	1348
1500	-	940 1210 1253	1134	170	1114
1200	-	1328 1199 1242	1256	66	1236
900	-	1177 1490 1199	1280	175	1269
600	-	853 1091 758	901	172	881
300	-	299 301 405	335	61	315
150	-	200 231 162	198	35	178
Negative Control	-	19 21 20 22 19	20		
Historical Control	-		22		
Positive Control	-	688 515 626	610		
Historical Control	-		611		
2NF 2 µg Specific Activity			1.51		

2NF -2-nitrofluorene

sl.tox - slight toxicity

Soluble organic fraction (SOF) = 179.7 mg

THE DETERMINATION OF THE PAH PARTITION RATIO AND THE NATURE OF MUTAGENS GENERATED BY CATALYTIC PURIFIERS

DSS Contract 03ST.23440-3-9196

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and

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February 1988

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ABSTRACT

Hi Vol samples collected downstream from diesels fitted with a Dieseler III and an Oxy Cat exhaust treatment system were analyzed using the Ames bioassay with Salmonella Typhimurium strain TA-98 without metabolic activation. The mutagenicity of the diesel exhaust extract from the Dieseler III and the Oxy Cat purifiers were comparable to that found when a PTX catalytic converter is on the diesel. The unexpectedly low mutagenicity found with the Dieseler III and Oxy Cat purifiers was attributed to the LHD cycle which did not have a significant low power component. Significant amounts of nitroPAHs are thought to be produced when the diesel particulate is stored and nitrated during a low power portion of the LHD cycle.

I N T R O D U C T I O N

Previous studies (1) have shown that the extract of the diesel exhaust particulate samples collected on Hi Vol filters downstream from a diesel fitted with a Dieseler III catalytic purifier is highly mutagenic. In fact, the mutagenicity of the diesel exhaust from a Dieseler III catalyst is approximately thirty times higher than that found with the newer PTX catalytic purifiers in the Ames bioassay using the Salmonella Typhimurium strain TA-98 without metabolic activation (TA-98 - S9). The higher mutagenicity of the diesel exhaust extract from a sample collected downstream from a diesel fitted with a Dieseler III catalyst has been tentatively attributed to the presence of a class of compounds called nitroPAHs. These highly mutagenic (2) nitroPAHs are thought to form when the diesel is operating at low power and the diesel particulate (soot) is stored in the catalyst. The PAHs on the diesel particulate stored in the catalyst are probably nitrated (converted into the highly mutagenic nitro- and dinitroPAHs, Figure 1) as the hot NO_2 in the exhaust passes over the particulate. Finally, the particulate containing the highly mutagenic (2) nitroPAHs is re-emitted from (blown out of) the catalyst into the mine air when the diesel is working at high power, eg., during the mucking portion of the LHD cycle.

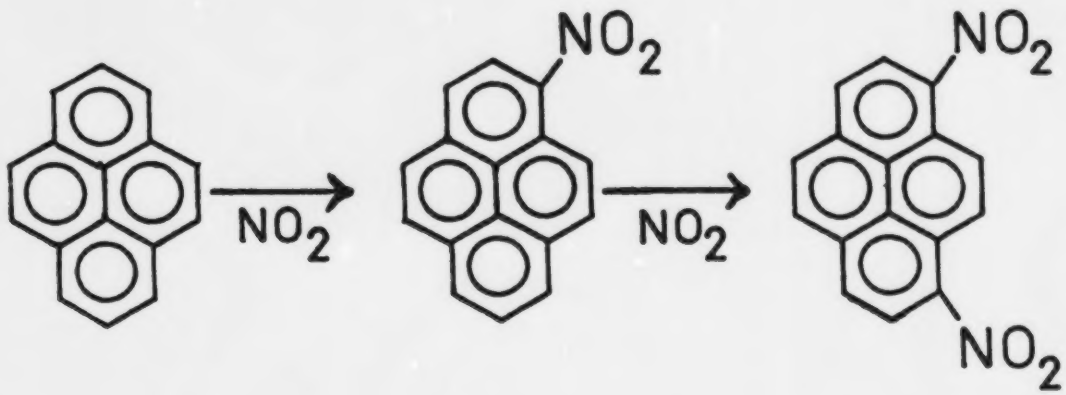

Figure 1. The mononitro-and dinitropyrene (nitroPAHs) formed in the nitration of pyrene and the mutagenicity of the nitropyrenes in the Ames bioassay using Salmonella Typhimurium strain TA-98 without metabolic activation.

The presence of nitroPAHs in the Dieseler III diesel exhaust extracts is also suggested by the much lower mutagenicity found in Ames bioassays using Salmonella strains that do not react with nitro compounds, Table 1 (1). The high mutagenicity of the diesel exhaust extract with tester strain TA-98 - S9, which reacts with nitroPAHs, is reduced markedly when the Ames bioassay is done using tester strains TA-98 NR which does not react with mononitroPAHs, TA-98 1,8DNP$_6$ which does not react with dinitroPAHs, and TA-98 NR/BR which does not react with either mono- or dinitroPAHs. The almost total reduction in the mutagenicity with the TA-98 NR/BR tester strain indicates that virtually all of the mutagenic response is due to the presence of nitroPAHs in the diesel exhaust extract.

This work was undertaken to confirm that the high mutagenicity of the extracts from the diesel exhaust samples from the Dieseler III purifier was, indeed, due to nitroPAHs and to identify these nitroPAHs.

Another aspect of this work was to determine whether the diesel exhaust emitted from a diesel fitted with an Oxy Cat purifier was also highly mutagenic and contained nitroPAHs. This was of interest because the Oxy Cat purifier, which was used in mines before the Dieseler III

Table 1. The mutagenicity of the extract from diesel exhaust samples collected downstream from a diesel fitted with a Dieseler III catalytic purifier as determined in a multistrain Ames bioassay without metabolic activation.

	Salmonella Typhiurium Strain			
	TA-98	TA-98 NR	TA-98 $1,8DNP_6$	TA-98 NR/BR
Revertants/m^3 in the mine air	1764	744	19.3	2.9

catalyst was sold, is similar in design to the Dieseler III catalyst.

R E S U L T S A N D D I S C U S S I O N

TEST SITE

The Hi Vol diesel exhaust samples required for this investigation of the mutagens released from Dieseler III and Oxy Cat catalytic purifiers were collected on the 1400 foot level at Inco Metals Company's Little Stobie Mine. A level plan of the test site is given in Figure 2.

The LHD cycle consisted of mucking the ore at the bottom of a 20% ramp, tramming up the ramp, and dumping it onto a train at the top of the ramp. The LHD cycle was different from normal in that the ore was mucked at the bottom of the ramp and had to be carried up a steep incline to the train. Thus, the diesel worked at high power during the mucking and while carrying the ore up the incline. The only low power portion of the LHD cycle was during the dumping (approximately 10 sec.), and as the diesel returned down the ramp to the muck pile.

AMES BIOASSAYS USING TA-98 WITHOUT METABOLIC ACTIVATION

Hi Vol filter samples were collected downstream from a JS 500 LHD diesel i) when it had no exhaust treatment device, ii) when it was fitted with a Dieseler III purifier and iii) when it had a Oxy Cat catalytic purifier

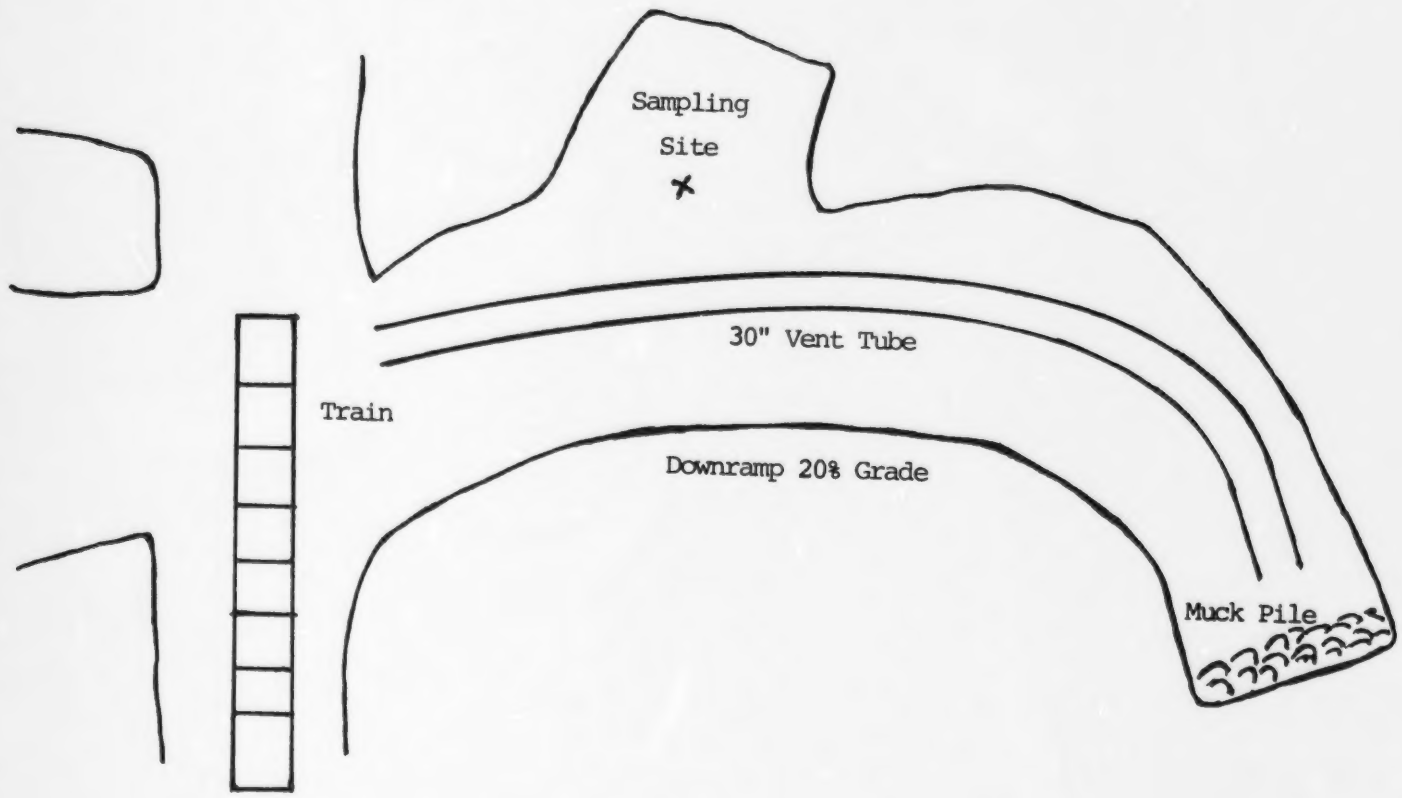

Figure 2. The level plan of the sampling site on the 1400 foot level of Inco's Little Stobie Mine.

as the exhaust treatment system. All of the samples were collected downstream from, but near, the mucking site because this is when any stored and nitrated particulate would be ejected from the catalyst. Four Hi Vol filter samples were collected downstream from the bare engine, eight samples were collected when the engine was fitted with the Dieseler III catalyst, and four samples were collected when the diesel had an Oxy Cat purifier in the exhaust system. All of the filter samples were halved and combined in pairs so that there were four (two sets of identical) bare engine samples, eight (four sets of identical) Dieseler III samples and four (two sets of identical) Oxy Cat samples. One sample of each identical set was analyzed in a one strain Ames bioassay with Salmonella strain TA-98 - S9. The Ames bioassay was used to determine whether the samples were highly mutagenic and contained sufficicent nitroPAHs to analyze.

The details of the sampling are given in Table 2 and the mutagenicity of the mine air as found in the Ames bioassay are presented in Table 3. The details of the Ames bioassays are in Appendix 1.

The results from the Ames bioassays, Table 3, show that the mutagenicity of the air downstream from the diesel fitted with a Dieseler III and an Oxy Cat purifier are not significantly different from the air downstream

Table 2. The sampling conditions for the diesel exhaust samples collected near the mucking site when the diesel was fitted with a Dieseler III, an Oxy Cat, and no exhaust treatment device.

Type of Catalytic Purifier	Sampling Time (min)	Sampling Rate (cfm)	Volume of of Air Sampled (m^3)	Volume of Air in Combined Sample (m^3)
$none_1$	76	44.0	96.84	96.03
$none_2$	76	44.5	95.77	96.03
$none_3$	76	46.0	99.01	97.39
$none_3$	76	44.5	95.78	97.39
$Dieseler\ III_1$	42	48.5	57.69	55.01
$Dieseler\ III_2$	42	44.0	52.34	55.01
$Dieseler\ III_3$	58	45.0	73.92	72.69
$Dieseler\ III_4$	58	43.5	71.45	72.69
$Dieseler\ III_5$	42	46.0	54.71	55.01
$Dieseler\ III_6$	42	46.0	55.31	55.01
$Dieseler\ III_7$	58	45.0	73.92	73.10
$Dieseler\ III_8$	58	44.0	72.27	73.10

Table 2 Cont. The sampling conditions for the diesel exhaust samples collected near the mucking site when the diesel was fitted with a Dieseler III, an Oxy Cat, and no exhaust treatment device.

Type of Catalytic Purifier	Sampling Time (min)	Sampling Rate (cfm)	Volume of of Air Sampled (m^3)	Volume of Air in Combined Sample (m^3)
$Oxy\ Cat_1$	49	47.9	66.47	66.40
$Oxy\ Cat_2$	49	47.8	66.33	66.40
$Oxy\ Cat_3$	31.5	48.5	43.27	42.38
$Oxy\ Cat_4$	31.5	46.5	41.48	42.38

Table 3. The mutagenicity as determined using tester strain TA-98 - S9 in the Ames bioassay of the diesel exhaust samples collected downstream from a mucking site when the diesel was operated with a Dieseler III catalyst, an Oxy Cat catalyst, and no exhaust treatment device.

Type of Catalytic Purifier	Volume of Air Sampled (m^3)	Extract Weight (mg)	Average Specific Activity (Rev./µg)	Mutagenicity in Revertants/m^3
none	96.30	53.6	0.70	390
none	97.39	58.3	0.60	359
			Average Mutagenicity	375
Dieseler III	55.01	18.5	0.78	262
Dieseler III	55.01	16.0	0.70	203
Dieseler III	72.69	18.1	0.74	184
Dieseler III	73.10	20.0	0.95	260
			Average Mutagenicity	227
Oxy Cat	66.40	19.4	0.54	158
Oxy Cat	42.38	17.7	0.65	272
			Average Mutagenicity	215

from the bare engine. In fact, the average mutagenicity of the air downstream from the diesel fitted with the Dieseler III and the Oxy Cat purifiers, 227 and 215 revertants/m^3, respectively, is approximately 40% less mutagenic than the air (375 revertants/m^3) collected downstream from the bare engine.

This result was unexpected because other work (1) had shown that the exhaust from a Dieseler III catalyst was highly mutagenic. In fact, the average mutagenicity of the air downstream from the mucking site when a Deutz diesel was fitted with a Dieseler III catalyst is 12,895 revertants/m^3 whereas the average mutagenicity of the air from the same engine fitted with a PTX catalytic purifier is only 465 revertants/m^3 (1).

The much lower mutagenicity found in this experiment may be the result of the LHD cycle (level plan) at the sampling site, Figure 2. In these experiments, the diesel mucked the ore at the bottom of a ramp. Then, it carried the ore up the ramp and dumped it onto the train. Thus, the diesel would have been working at or near maximum power for most of the LHD cycle. As a result, the diesel particulate would have been blown out of the purifier at almost every stage of the LHD cycle and would only have been trapped in the catalyst for a very short portion of the LHD cycle. Since the particulate would be trapped and

re-emitted very rapidly, the PAHs on the diesel particulate trapped in the catalyst would only be exposed to the hot NO^2 in the exhaust for a very short time and very little of the PAHs would have been nitrated. As a result, little or no nitroPAHs would have been formed and the mutagenicity of the exhaust would be low, approaching that of the bare engine.

Because the mutagenicity of the samples was low, it was surmised that the amount of the highly mutagenic nitroPAHs would be too small to be analyzed. As a result, the project was stopped and the samples were not sent for nitroPAH analysis as had been planned.

A C K N O W E L E G M E N T S

The authors would like to thank Mr. Bill Elliott and Inco Metals Co. for allowing us to carry our this research in their Little Stobie Mine. We also wish to acknowledge Mr. Claude Bourre's assistance with the sampling.

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A P P E N D I X I

TABLE : 1

Bare Engine A
Salmonella Tester Strain TA-98

	CONCENTRATION ug / PLATE	S-9 MIX	HISTIDINE REVERTANTS			MEAN	STD +/-	NET. REV.
	400	_	233	249	233	238	9	192
	300	_	210	189	166	188	22	142
	250	_	176	158	165	166	9	120
*	200	_	194	164	180	179	15	133
*	150	_	160	148	149	152	7	106
*	100	_	96	89	94	93	4	47
*	50	_	74	74	86	78	7	32
*	10	_	53	40	51	48	7	2
NEGATIVE CONTROL		_	49	42	46 40 51	46	5	
HISTORICAL VALUE		_				31		
POSITIVE CONTROL		_	416	446	443	435	17	
HISTORICAL VALUE		_				619		
COMPOUND		2 Nitrofluorene 2 ug / plate						
MUTAR						6.2		
SPECIFIC ACTIVITY						0.7		

Table : 2

Bare Engine B
Salmonella Tester Strain TA-98

	CONCENTRATION ug / PLATE	S-9 MIX	HISTIDINE REVERTANTS			MEAN	STD +/-	NET. REV.
	400	_	156	204	195	185	26	139
	300	_	130	180	200	170	36	124
	250	_	159	151	153	154	4	108
	200	_	101	146	151	133	28	87
*	150	_	131	128	164	141	20	95
*	100	_	86	106	101	98	10	52
*	50 3	_	73	69	79	74	5	28
*	10	_	45	47	65	52	11	6
NEGATIVE CONTROL		_	49	42	46 40 51	46	5	
HISTORICAL VALUE		_				31		
POSITIVE CONTROL		_	416	446	443	435	17	
HISTORICAL VALUE		_				619		
COMPOUND		2 Nitrofluorene 2 ug / plate						
MUTAR						4.5		
SPECIFIC ACTIVITY						0.6		

* point used to calculate specific activity

ORF

TABLE : 3

Dieseler III A
Salmonella Tester Strain TA-98

	CONCENTRATION ug / PLATE	S-9 MIX	HISTIDINE REVERTANTS			MEAN	STD +/-	NET. REV.
	400	-	337	309	344	330	19	284
	300	-	217	236	280	244	32	198
*	250	-	220	226	266	237	25	191
*	200	-	198	209	224	210	13	164
*	150	-	169	119	174	154	30	108
*	100	-	101	101	98	100	2	54
*	50	-	89	105	99	98	8	52
*	10	-	50	40	60	50	10	4
	NEGATIVE CONTROL	-	49	42	46 40 51	46	5	
	HISTORICAL VALUE	-				31		
	POSITIVE CONTROL	-		416	446 443	435	17	
	HISTORICAL VALUE	-				619		
	COMPOUND		2 Nitrofluorene 2 ug / plate					
	MUTAR					9.2		
	SPECIFIC ACTIVITY					0.78		

Table : 4

Dieseler III B
Salmonella Tester Strain TA-98

	CONCENTRATION ug / PLATE	S-9 MIX	HISTIDINE REVERTANTS			MEAN	STD +/-	NET. REV.
	400	-	279	336	302	306	29	260
	300	-	241	245	231	239	7	193
*	250	-	246	242	221	236	13	190
*	200	-	236	169	199	201	33	155
*	150	-	187	153	202	181	25	135
*	100	-	100	118	120	113	11	67
*	50	-	93	115	103	104	11	58
*	10	-	55	40	38	44	9	-
	NEGATIVE CONTROL	-	49	42	46 40 51	46	5	
	HISTORICAL VALUE	-				31		
	POSITIVE CONTROL	-		416	446 443	435	17	
	HISTORICAL VALUE	-				619		
	COMPOUND		2 Nitrofluorene 2 ug / plate					
	MUTAR					8.4		
	SPECIFIC ACTIVITY					0.7		

* point used to calculate specific activity

ORF

TABLE : 5

Dieseler III C
Salmonella Tester Strain TA-98

	CONCENTRATION ug / PLATE	S-9 MIX	HISTIDINE REVERTANTS			MEAN	STD +/-	NET. REV.
	400	-	276	257	317	283	31	237
*	300	-	275	281	261	272	10	226
*	250	-	195	225	225	214	19	168
*	200	-	162	237	230	210	41	164
*	150	-	146	168	178	164	16	118
*	100	-	125	114	109	116	8	70
*	50	-	83	97	86	89	7	43
*	10	-	54	43	44	47	6	1
	NEGATIVE CONTROL	-	49	42	46 40 51	46	5	
	HISTORICAL VALUE	-				31		
	POSITIVE CONTROL	-		416	446 443	435	17	
	HISTORICAL VALUE	-				619		
	COMPOUND		2 Nitrofluorene 2 ug / plate					
	MUTAR					7.6		
	SPECIFIC ACTIVITY					0.74		

Table : 6

Dieseler III D
Salmonella Tester Strain TA-98

	CONCENTRATION ug / PLATE	S-9 MIX	HISTIDINE REVERTANTS			MEAN	STD +/-	NET. REV.
	400	-	248	246	253	249	4	203
	300	-	146	234	234	205	51	154
	250	-	200	234	169	201	31	155
	200	-	145	195	202	181	31	135
*	150	-	170	206	177	184	19	138
*	100	-	105	133	136	125	17	79
*	50	-	89	93	91	91	2	45
*	10	-	52	45	48	48	4	2
	NEGATIVE CONTROL	-	49	42	46 40 51	46	5	
	HISTORICAL VALUE	-				31		
	POSITIVE CONTROL	-		416	446 443	435	17	
	HISTORICAL VALUE	-				619		
	COMPOUND		2 Nitrofluorene 2 ug / plate					
	MUTAR					6.5		
	SPECIFIC ACTIVITY					0.95		

* point used to calculate specific activity

ORF

TABLE : 7

Oxy Cat A
Salmonella Tester Strain TA-98

CONCENTRATION ug / PLATE	S-9 MIX	HISTIDINE REVERTANTS			MEAN	STD +/-	NET. REV.
* 400	_	336	323	317	325	10	288
* 300	_	230	241	207	226	17	189
* 250	_	224	191	229	215	21	178
* 200	_	123	270	197	197	74	160
* 150	_	168	193	181	181	13	144
* 100	_	137	127	171	145	23	108
* 50	_	123	113	110	115	7	78
NEGATIVE CONTROL	_	45	29	39 42 32	37	7	
HISTORICAL VALUE	_				31		
POSITIVE CONTROL	_	630	688	650	656	29	
HISTORICAL VALUE	_				619		
COMPOUND		2 Nitrofluorene		2 ug / plate			
MUTAR					9.1		
SPECIFIC ACTIVITY					0.54		

Table : 8

Oxy Cat C
Salmonella Tester Strain TA-98

CONCENTRATION ug / PLATE	S-9 MIX	HISTIDINE REVERTANTS			MEAN	STD +/-	NET. REV.
* 400	_	419	317	469	402	77	365
* 300	_	312	271	232	272	40	235
* 250	_	256	177	267	233	49	196
* 200	_	262	339	227	276	57	239
* 150	_	214	295	203	237	50	200
* 100	_	198	151	160	170	25	133
* 50	_	131	149	141	140	9	103
NEGATIVE CONTROL	_	45	29	39 42 32	37	7	
HISTORICAL VALUE	_				31		
POSITIVE CONTROL	_	630	688	650	656	29	
HISTORICAL VALUE	_				619		
COMPOUND		2 Nitrofluorene		2 ug / plate			
MUTAR					11.8		
SPECIFIC ACTIVITY					0.65		

* point used to calculate specific activity